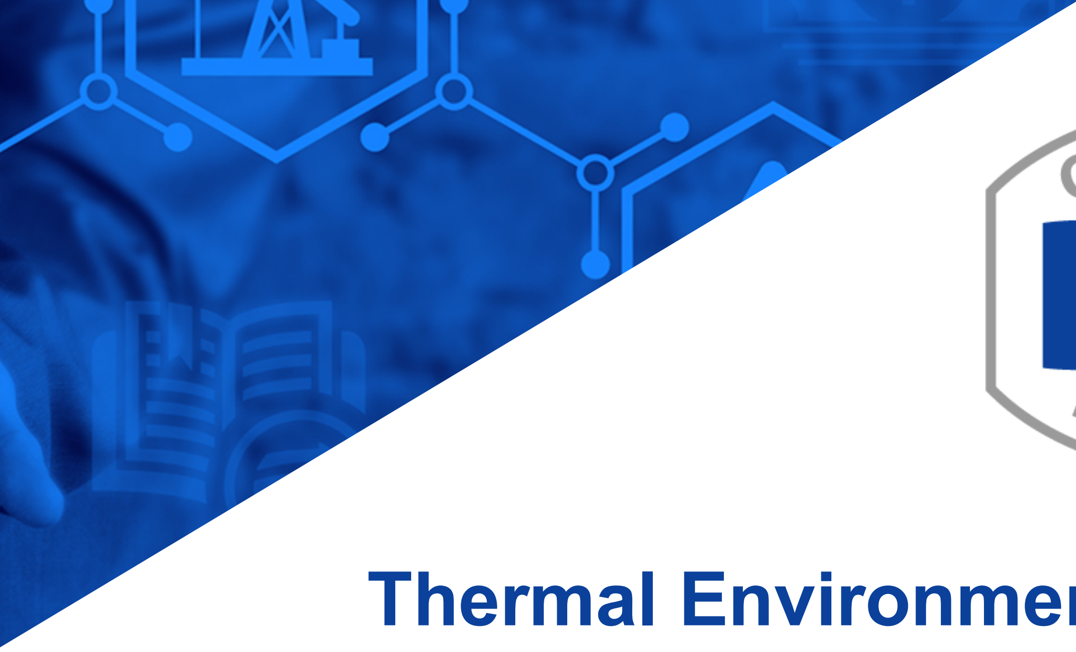

OHS Body of Knowledge

Thermal Environment

Core Body of Knowledge for the
Generalist OHS Professional

Second Edition, 2019

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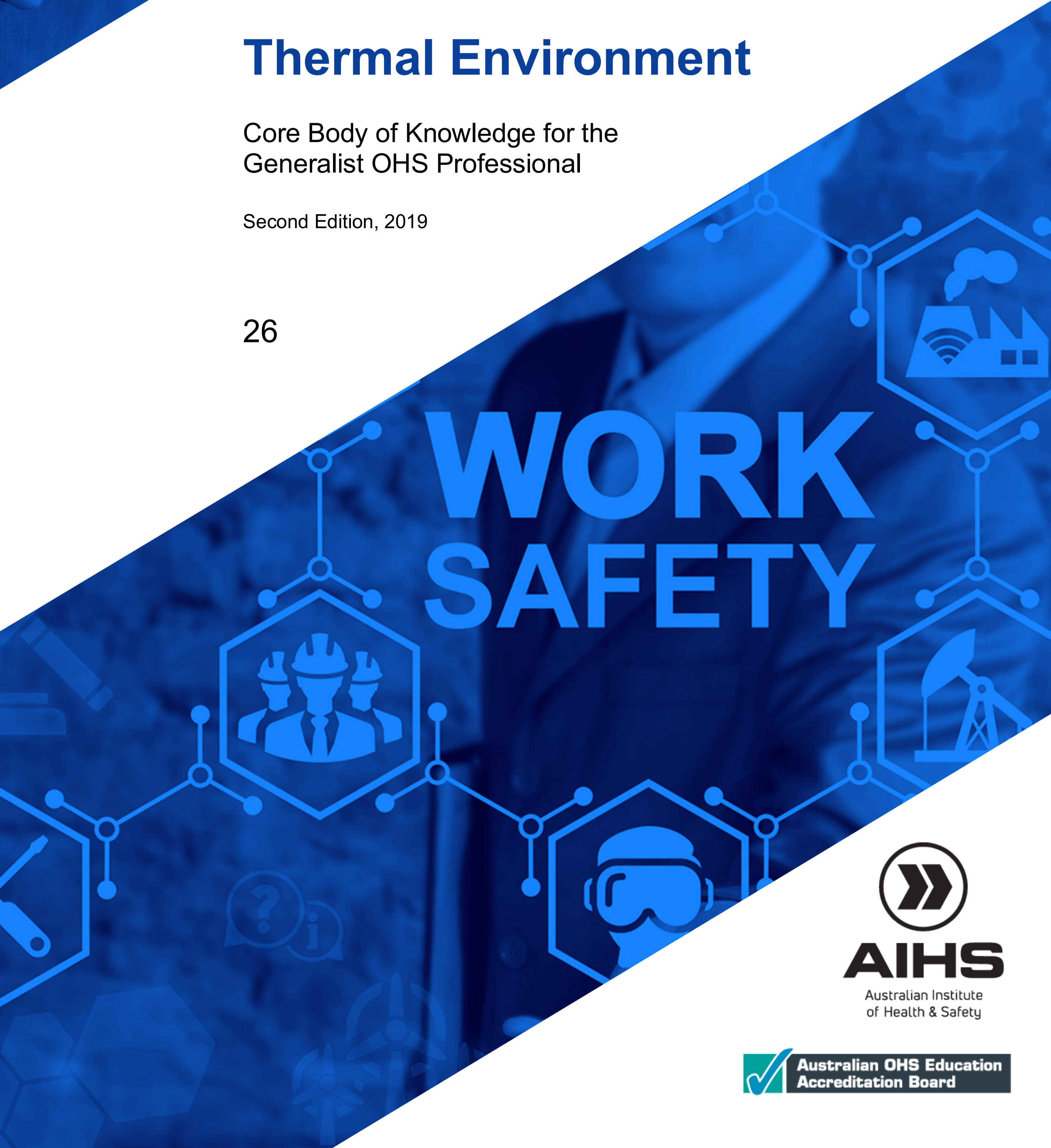

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The *OHS Body of Knowledge* forms the basis of the AIHS OHS capability agenda and informs the other platforms of the agenda: education assurance through accreditation; role clarity, capability assurance through individual certification and continuing professional development.

Thus, the *OHS Body of Knowledge* is strategically important to the AIHS and vital for the profession.

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Thermal Environment

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Thermal Environment

Abstract

The complex range of hazards associated with the thermal environment is widely acknowledged as a serious Occupational Health and Safety (OHS) issue. Exposure to extreme heat or cold can result in illness, injury and, in extreme cases, death. While high-risk situations will require specialist occupational hygiene advice, the generalist OHS professional should have an understanding of the impact of hot and cold environments, risk assessment methods and the regulatory framework as a basis for advising on, implementing, and monitoring controls. This chapter presents fundamental information about potential health and injury effects, assessment and control methods and, given the relevance of heat exposure to Australian working conditions, outlines a three-tiered approach to the assessment of heat exposure.

Keywords

thermal environment, heat, cold, hypothermia, hyperthermia, burn

Contextual reading

Readers should refer to 1 *Preliminaries* for a full list of chapters and authors and a synopsis of the OHS Body of Knowledge. Chapter 2, *Introduction* describes the background and development process while Chapter 3, *The OHS Professional* provides a context by describing the role and professional environment.

Terminology

Depending on the jurisdiction and the organisation, Australian terminology refers to 'Occupational Health and Safety' (OHS), 'Occupational Safety and Health (OSH) or 'Work Health and Safety' (WHS). In line with international practice this publication uses OHS with the exception of specific reference to the Work Health and Safety (WHS) Act and related legislation.

Jurisdictional application

This chapter includes a short section referring to the Australian model work health and safety legislation. This is in line with the Australian national application of the *OHS Body of Knowledge*. Readers working in other legal jurisdictions should consider these references as examples and refer to the relevant legislation in their jurisdiction of operation.

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1 Introduction

The management of thermal exposures has long been an issue for the Occupational Health and Safety (OHS) professional. The exposure of workers to extreme heat or cold can result in serious illnesses and injuries, and even death. Risk management is complicated by not only the vagaries of the environment, but also by the variability of the human body. This complexity cannot always be eliminated and often requires specialist expertise; thus the generalist OHS professional should have access to specialist occupational hygiene advice in high-risk situations. Nevertheless, there is a role for the generalist OHS professional to utilise some readily available tools and a systematic assessment process to identify the key issues and implement effective controls.

Consequently, this chapter focuses on the health and injury effects associated with exposure to the extremes of the thermal environment, risk assessment, and the identification and application of controls to protect workers from exposure to the effects of heat and cold.[1] It does not provide information relating to management of thermal comfort.[2] Furthermore, while this chapter provides some information relevant to working in cold environments, it is predominantly concerned with exposure to heat as this is most relevant for the Australian climate. Heat stress, a prominent industry concern, impacts directly on the individual and is an indirect contributor to many incidents in Australian workplaces. This chapter presents a systematic three-tiered approach to risk assessment in hot environments.

1.1 Definitions

Heat stress occurs “when a person’s environment (air temperature, radiant temperature, humidity and air velocity), clothing and activity interact to produce a tendency for body temperature to rise” (Parsons, 1998). *Cold stress* has been defined as “a thermal load on the body under which greater than normal heat losses are anticipated and compensatory thermoregulatory actions are required to maintain the body thermally neutral” (Holmer, 1998). The US Center for Disease Control and Prevention explained:

> Workers who are exposed to extreme heat or work in hot environments may be at risk of **heat stress**. Exposure to extreme heat can result in occupational illnesses and injuries. Heat stress can result in heat stroke, heat exhaustion, heat cramps, or heat rashes. Heat can also increase the risk of injuries in workers as it may result in sweaty palms, fogged-up safety glasses, and dizziness…Workers at risk of heat stress include outdoor workers and workers in hot environments such as firefighters, bakery workers, farmers, construction workers, miners, boiler room workers, factory workers, and others. (CDC, 2011a)

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[1] This chapter assumes that the reader is familiar with ‘thermal science,’ including convection, radiation and conduction, and basic physiology as described in *OHS BoK* 14 Foundation Science.

[2] For more information on thermal comfort, see ANSI/ASHRAE (2010).

> Workers who are exposed to extreme cold or work in cold environments may be at risk of **cold stress**. Extreme cold weather is a dangerous situation that can bring on health emergencies in susceptible people, such as those without shelter, outdoor workers, and those who work in an area that is poorly insulated or without heat…Prolonged exposure to cold will eventually use up your body's stored energy. The result is hypothermia, or abnormally low body temperature. A body temperature that is too low affects the brain, making the victim unable to think clearly or move well. (CDC, 2011b)

In addition, the following CCOHS (2008) definitions are relevant to a discussion on thermal environment:

Acclimatization – Physiological changes which occur in response to several days of heat exposure and make the body accustomed to a hot environment.

Convection – Process of heat exchange between the body and the surrounding air or fluid as a result of bulk flow of that air or fluid.

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

Heat cramps – Painful and often incapacitating cramps in muscles. Heat cramps are caused by depletion of salt in the body as a result of heavy sweating, and ingestion of water without replacing salt.

Heat exhaustion – Weakness, lassitude, dizziness, visual disturbance, feeling of intense thirst and heat, nausea, vomiting, palpitations, tingling and numbness of extremities after exposure to a hot environment.

Heat hyperpyrexia – Rise in body temperature with moist skin and mental dysfunction, caused by exposure to an extremely hot environment.

Heat rash (prickly heat or milliaria) – An itchy rash of small raised red spots on the face, neck, back, chest and thighs caused by a hot and moist environment.

Heat strain – Physiological and behavioural responses of the body as a result of heat exposure.

Heat stroke – Acute illness caused by overexposure to heat. Symptoms are dry, hot skin, high body temperature (usually over 41ºC] and mental dysfunction.

Heat syncope – Temporary loss of consciousness [fainting] induced by insufficient flow of blood to the brain. Recovery is normally prompt and without any long-term ill effects.

Metabolic rate – Rate of energy (heat) production of the body which varies with the level of activity.

Natural Wet Bulb Temperature – Air temperature measured using a thermometer in which the bulb is covered with wet cotton wick and cooled by the natural movement of air.

Nausea – The feeling that one is about to vomit as experienced in seasickness.

Radiation (heat) – Transfer of heat between hot and cold bodies without contact between them.

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

2 Historical context

Goldman (2001, p. 4) revealed that the effects of hot environments were documented in the earliest writing; by 3000 BC, the Romans, Egyptians and Greeks had linked the appearance of Sirius, the dog star, with "ushering in the 'dog days' of summer…[and] bringing on fever in men and madness in dogs." There are also references to early controls; for example:

> The Roman legionary used an early form of auxiliary cooling, inserting rushes into his head gear and keeping them wet with water...[and used] auxiliaries to carry as much of the legionnaires' load, and do as much of the engineering digging as possible, thus sparing the fighting edge of the legion (Goldman, 2001, p. 5).

In 1774 Sir Charles Blagden (Royal Society 1775), discussed a number of experiments undertaken in a heated room in which he commented on "the wonderful power with which the animal body is endued, of resisting heat greatly greater than its own temperature".

In the early 1900s a number of authors wrote on the effects of heat and humidity on workers (Moss et al., 1923; Young et al., 1920; Vernon et al., 1932). 1925 saw the development of the effective temperature index (Houghton & Yagloglou, 1924), a key milestone in the assessment of thermal comfort, then in 1957 an investigation into casualties during training in the US Navy led to the development of the now well-known wet bulb globe temperature index (WBGT) (Yaglou & Minard, 1957). Hunt (2011) in describing the mining industry's long-term struggle with heat stress, cited a 1930 incident rate of fatality from heat stroke in South African mines of 1.5 per thousand workers.

Similarly, there is very early evidence of the health effects of cold environments. Patton (2001) chronicled the effects of cold stress on warfare, commencing with an account of the Battle of Cunaxa near Babylon in the winter of 401–400 BC when 6,000 of Athenian Xenophon's 10,000 men died from cold exposure and frostbite. The statistics remained large-scale through the centuries. For example, there were more than 15,000 cold injuries during the American Civil War (1861–1865); in World War I the British army sustained 115,000 cold and frostbite injuries, and 2000 Russians died from frostbite and cold exposure during two nights in 1916; and in World War II cold injuries numbered in the millions (Patton, 2001). The magnitude of cold-stress-related morbidity and mortality during World War II stimulated significant programs of research "to solve the problems of the etiology and treatment of frostbite, trench foot and hypothermia" (Patton, 2001, p. 335) that have resulted in "rapid rewarming in the field" (p. 342) as well as physical and psychological preparation for the elements.

Whilst there has been significant advances made in the control and management of both hot and cold environments since these early days there continues to be an issue with the occurrence of thermally related injuries and illnesses in current times.

3 Extent of the problem

Australian workers' compensation claim data for 2016-17 (SWA, 2018) combines the agencies of injury 'heat, electricity and other environmental factors' and so provides little indication of the extent of the problems associated with working in hot or cold thermal environments, consequently this impact is often underestimated. The human body's complex response to hot or cold environments includes subtleties of physiological/pathological change that are unlikely to be reflected in workers' compensation data. Indeed, due to under-reporting, misdiagnosis and lack of public awareness of the many ways it can contribute to death, illness or injury, cold stress has been identified as "possibly one of the most underrated killers in modern medicine" (Lloyd, 1986, p. 3).

The Occupational Health and Safety Council of Ontario (OHSCO, 2009, p. 3) indicated that heat stress is likely to be a concern in all workplaces where 'yes' is the answer to one or more of the following questions:

- Has anyone been affected by heat in your workplace?
- Are fans needed to keep workers cool?
- Is work done in direct sunlight?
- Are there heat-producing processes or equipment in the workplace?
- Do workers wear extra clothing/protective equipment that can make them hot (e.g. overalls, respirators, hard hats, etc.)?
- Have workers ever expressed concern about heat in the workplace?

Shearing is an extreme example of a heat-affected occupation; it is often undertaken in uninsulated corrugated iron sheds and shearers are susceptible to heat rash, heat exhaustion and heat stroke (Gunn et al., 1995). Also, despite improvements in working conditions, workers in the mining industry remain particularly vulnerable to heat stress (Hunt et al., 2013). In a study of heat exhaustion in a deep underground mine in Australia, Donoghue, Sinclair and Bates (2000) found that while the average annual incidence was relatively low (43 cases per million worker-hours underground; a total of 106 cases), it was much higher during summer (e.g. 147 cases per million worker-hours underground in the month of February).

4 Understanding the impact of hot environments

Understanding the impact of working in hot environments requires some knowledge of the physiological responses of the body and the nature of the relevant acute and chronic health effects. This knowledge provides a basis for risk assessment, which is presented as a three-tiered approach that considers the complexity of the situation, the level of risk and the availability of expert advice. A brief summary of the legislative requirements and standards sets the context for discussion of relevant controls.

4.1 Physiological response[3]

4.1.1 Homeostasis

Homeostasis is “the maintenance of a constant internal environment within the body”; it includes not only control of the body temperature, but also control of the water balance of the blood, the blood sugar level and the blood urea level (Givens & Reiss, 2002, p. 56).

The human body operates within a very narrow core temperature band. While there are diurnal variations, normal internal core body temperature usually ranges from 36.8°C to 37.2°C. To maintain this internal temperature balance, any heat impact on the body, whether from external environmental conditions or generated as a result of work performed by the individual, must be balanced by an equivalent heat loss from the body. If this does not occur, there is a net heat gain and heat stress is experienced by the individual (see, for example, BOHS, 1996).

The body’s heat balance process is often likened to a car engine: the organs and muscles are the engine that generates heat; the blood is the coolant that takes the heat from the core to the skin, which is the radiator; and the hypothalamus in the brain is the body’s thermostat.

Consider the following example:

A person working in an air-conditioned workshop starts to generate heat. The core temperature begins to rise and the hypothalamus (the thermostat) signals increased heart rate and dilation of blood vessels at the periphery so that a greater volume of blood is distributed to the surface of the skin. Once the blood reaches the skin (often making the person appear ‘flushed’), the heat is transferred to the cool environment by convection, and the blood temperature lowers and is returned

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[3] See also *OHS BOK* 7 The Human as a Biological System.

to the core where the core temperature drops. This is a simple, but effective process for cooling the body. However, if the outside temperature is elevated, the process of heat transfer to the external environment is not as efficient. In this case, the body begins to sweat, and as the sweat evaporates the skin is cooled, which in turn cools the blood and hence lowers the core temperature. In principle, this is similar to the canvas water bag on the front of a ute or the old bush fridge in a canvas bag. Sweat that drips off has no cooling effect and sweat that soaks a shirt has a much-reduced cooling effect.

The most effective means of regulating temperature is via this evaporation of sweat, which may account for up to 98% of the cooling process (Werner et al., 1993). If fluid is not replaced, the individual can experience reduced capacity for physical work, fatigue and psychological changes:

- Dehydration of 1 to 2% of body weight results in a 6 to 7% reduction in physical work rate.
- Dehydration of 3 to 4% of body weight results in a 22% to 50% reduction in work rate, for “moderate” and “hot” environments, respectively.
- Mental performance (mental function, visuomotor skills and arithmetic tests) begins to decrease at 2% dehydration and thereafter is proportional to the degree of further dehydration (Brake, 2001, p. 278).

4.1.2 Acclimatisation

Heat acclimatisation is a complex physiological process that occurs over time as the body adjusts to the thermal environment. A heat-acclimatised state is defined as “an organism’s ability to perform increased work in the heat because of improvements in heat dissipation brought on by repeated mild elevations in core temperature” (Amorim & Moseley, 2010, p. 75). The acclimatisation process results in greater efficiency of the body to control its internal temperature. Benefits of heat acclimatisation documented by Bricknell (1996) have been summarised as:

- More finely tuned sweating reflexes, with earlier increased sweat production rate at lower electrolyte concentrations
- Lower core and skin temperatures than at the beginning of exposure
- Increase in plasma volume of up to 16% over the first 3-5 days
- Earlier initiation of vasodilation of the blood vessels in the skin (Pryor et al., 2018)
- More stable and better regulated blood pressure with lower pulse rates, and
- Improved productivity and safety (Di Corleto, Coles & Firth, 2003).

Each physiological change associated with acclimatisation (e.g. cardiovascular stability, fluid and electrolyte balances, sweat rates and temperature responses) has its own rate of change during this process. Heat acclimatization is as a result of the combination of exercise/work and heat usually >30°C (>86°F) over several repeated or extended exposures. When these two are not combined acclimatisation will occur more slowly. In general, much of the acclimatisation process occurs in the first four to seven days but not all of the above benefits are achieved at the same time (Pryor et al., 2018). The majority of benefits will usually be achieved within two weeks.

While the general consensus is that heat acclimatisation is gained faster than it is lost, less is known about the time required to lose acclimatisation. Brake, Donoghue and Bates (1998) suggested that loss of acclimatisation occurs over 7 to 21 days. Generally for Monday-to-Friday workers, the weekend loss is transitory and quickly made up, such that by Tuesday or Wednesday an individual is as well acclimatised as they were on the preceding Friday. If, however, there is a week or more of no exposure, loss is such that the regain of acclimatisation requires the usual 4 to 7 days (Bass, 1963).

An acclimatisation period is recommended for any new workers to site or workers returning from extended leave (i.e. >14 days) in a more temperate climate (Brake, Donoghue & Bates, 1998). It should be noted that individuals differ in their ability to acclimatise to heat.

4.1.3 Hydration and fluid requirements

Hydration status is a key factor in the ability of the human body to function efficiently in a hot thermal climate. The total body water mass is approximately 60% (Parsons, 2003); this level constantly varies when work is undertaken in hot environments. Fluids are lost via several routes, including sweating, evaporation from the respiratory tract, and excretion. Rehydration of lost fluids is integral to effective management of work in these adverse conditions. Ensuring that employees maintain a sufficient water intake to counter losses associated with sweat evaporation in hot environments has always been an issue. Consistently, research has shown that relying purely on the thirst mechanism to maintain fluid volumes is ineffective, and often results in 'involuntary dehydration' (e.g. Greenleaf, 1982; Sawka, 1988). Many studies have been conducted to identify an ideal replacement fluid that is palatable and provides a rapid rate of absorption into the body (see, for example, Murray, 2005). Palatability should not be underestimated; colour, odour, temperature and taste are critical to palatability and intake (e.g. Greenleaf, 1992; Holmes, n.d.).

Taken in frequent small amounts, water is the simplest and most readily absorbed fluid: "Research has established that fluid requirements during work in the heat that lasts less than 90 minutes can be met by drinking adequate amounts of plain water" (Nevola, 1998; Nevola, Staerck & Harrison, 2005). Particularly in the case of an acclimatised individual, the salt levels lost are usually replaced by the salt content of the average diet.

For hot-environment work of 90-240 minutes duration, consideration should be given to the inclusion of fluid that contains some form of carbohydrate additive of less than 7% concentration. For work periods exceeding 240 minutes, fluids should also be supplemented with electrolytes, including sodium (~20-30 mmol/L) and trace potassium (~5 mmol/L) to replace those lost in sweat. There are numerous commercial electrolyte-replacement drinks available with varying levels of sodium, potassium, carbohydrates and other additives. Their suitability should be assessed in light of the requirements of the specific situation. Alcohol should be avoided; as it can have a diuretic effect (increased urine production) and hence increase fluid loss, leading to dehydration and hindering rehydration before and after work (e.g. Brake, Donoghue & Bates, 1998; OHSCO, 2009; SDA, 2009.)

Medication can also impact on the body's ability to manage heat stress and should be taken into consideration. Diuretics will impact on the fluid balance whilst antihistamines may inhibit the sweating process, and some anti-inflammatories may interfere with thermoregulation. Medications which can affect blood pressure, i.e. beta blockers, may also lower heat tolerance as they can reduce the cooling ability of an individual by preventing dilation of the blood vessels in the skin.[4]

4.2 Acute health effects

Initial symptoms of heat strain – deterioration of concentration and fine motor skills and, in some cases, exhaustion – may start to manifest within a rise in core body temperature of 2°C. Heat stroke can begin when core body temperature reaches 40°C with death possible from 42°C (Leithead & Lind 1964). Indeed, the World Health Organization (WHO, 1969) recommended that a core temperature of 38°C not be exceeded during heavy labour. Heat illnesses can range from prickly heat, heat cramps, heat syncope (fainting) and dehydration to the more serious heat exhaustion and heat stroke. There is large variability in the response of individuals to hot conditions. Some individuals may be seriously affected by a body temperature of less than 39°C, whereas there have been documented instances of body temperatures exceeding 40°C without significant impairment of function (Hanson et al., 2000).

4.3 Chronic health effects

Chronic heat illnesses can be grouped into those that occur:

- Following an acute heat illness, e.g. reduced heat tolerance, muscle soreness after heat cramp, chronic heat exhaustion after acute heat exhaustion, cellular damage in organs after heat stroke
- Following working in hot conditions for weeks, months or years, e.g. chronic heat exhaustion symptoms such as headache, sleep disturbance, tachycardia (abnormal rapid heart rate) and nausea after several months in a hot job; hypertension, reduced

[4] Tables detailing responses to specific drugs in relation to heat and cold exposures can be found in BOHS Technical Guide No 12 (BOHS. 1996).

libido, myocardial damage and hypochromemia (low levels of chloride) after many years in a hot job

- Among people living in hot regions of the world, e.g. frequent skin diseases, sleep disturbance, psychoneurosis (tropical lethargy) and anhidrotic heat exhaustion in the tropics; kidney stones and anhidrotic heat exhaustion in the desert (Dukes-Dobos, 1981).

The increasing incidence of chronic kidney disease at almost epidemic levels in the hot coastal communities of Central America (Peraza et al., 2012; Roncal-Jiminez et al., 2014; Bodin et al., 2016) are being linked to recurrent dehydration. In addition some, liver, heart, digestive system, central nervous system, skin conditions and alterations in gestation length have been linked to long-term heat exposure (see, for example, Porter, Thomas & Whitman, 1999) and the evidence to support these links is becoming more evident.

4.4 Other hazards

Because heat stress can contribute to fatigue, its control is of particular importance in tasks of a critical safety nature (see, for example, WorkSafe Victoria, 2017). Furthermore, higher summer temperatures may be partially responsible for increased accident and injury incidence among workers in the mining and munitions industries and physically active individuals (Chrenko, 1974; Knapik et al., 2002).

Whilst the focus is often on heat illnesses, studies have linked workers exposure to an increased risk of accidents and injuries within the workplace. These include injuries ranging from superficial injuries through to fractures and amputations (Xiang et al., 2014: Martinez-Solanas et al., 2018; Tawatsupa et al., 2013; Varghese et al., 2019).

A number of studies have found that working in elevated temperatures can result in significant productivity losses (Kjellstrom et al., 2009; Sahu et al., 2013; Flouris et al., 2018). Productivity losses have been estimated at 2% per degree Celsius above 25ºC (Seppanen et al., 2003). In an Australian study reviewing estimates of self-reported absenteeism and reductions in work performance as a result of heat, there was a projected annual economic burden cost of approximately US$6.2 billion (Zander et al., 2015).

4.5 Risk assessment and assessing the thermal environment

Six basic factors can be used to define an individual's thermal environment.

Environmental factors:

- Air temperature
- Radiant temperature
- Air velocity
- Humidity

Personal factors:

- Clothing insulation
- Metabolic heat (HSE, n.d.).

These factors are considered in a three-tiered approach to assessment of heat exposure that has been designed to be applicable to a range of scenarios where the level applied is dependent on the severity and complexity of the situation (Di Corleto, 1998). The risk-assessment tiers require increasing levels of technical expertise. Whilst a Level 1 assessment could be undertaken by a variety of individuals with minimal or no technical skills, a Level 2 assessment requires a higher level of skill such as that of an OHS professional and in some cases specialist skills. A Level 3 assessment should be restricted to those with specialist knowledge and skills such as occupational physicians, experienced occupational hygienists or physiologists.

4.5.1 Level 1: Basic assessment

The first, or basic, level of thermal risk assessment as detailed in the Australian Institute of Occupational Hygienists *Heat Stress Standard* (Di Corleto, Coles & Firth, 2003) is a qualitative assessment that does not require specific technical skills in its application or interpretation. It was developed for use by frontline workers to assist them to better understand the mechanisms and impacts of thermal assessments. Level 1 assessment involves a series of questions relating to parameters that will impact the individual's heat stress; responses are assigned a numerical value and weighted according to potential impact on the thermal load. The final numerical value is compared to a predetermined scale that rates the overall heat stress potential.[5] Asking the assessor to rate specific parameters impacting on thermal stress highlights the many aspects of the work environment that need to be considered (i.e. not just a single dry bulb temperature). Undertaken as part of a walk-through survey with the worker, it can be a useful and powerful tool in training and education. In the original version of the Basic Thermal Assessment developed by the author there was no actual measurement required; use of the Wet Bulb Globe Thermometer (WBGT) temperature in the equation was added to supplement the subjective and qualitative

[5] See Appendix 1: Basic Thermal Risk Assessment.

nature of the assessment with some quantification. This has recently been replaced with the Apparent Temperature for greater simplicity and ease of use. Appendix 1 outlines the AIOH Thermal Risk Assessment Guide suitable for use at Level 1.

Various basic risk-assessment programs have been developed that include additional parameters such as urine specific gravity, hydration levels and decision matrices (Bates, Lindars & Hawkins, 2008). More recently we have seen the introduction of phone/tablet apps such as the 'Thermal Risk' app based on the AIOH basic thermal risk assessment (Di Corleto, Firth & Matè 2013) which can be downloaded onto a mobile phone or tablet for use in the field. It requires the user to answer a series of questions and to enter air temperature and humidity as input. The app can then provide an initial idea on potential issues and controls.

4.5.2 Level 2: Thermal assessment using a heat stress index

Level 2 assessment takes a more quantitative approach requiring the measurement of several environmental and personal parameters, such as dry bulb and globe temperatures, relative humidity and air velocity, and estimation of metabolic work load and clothing insulation. These parameters are used in conjunction with a heat stress index to determine allowable exposure times. Predicted Heat Strain (PHS) or Thermal Work Limit (TWL) – the so-called 'rational indices' – are normally based on the human heat balance equation (see Parsons, 2003), and attempt to model various important physiological parameters that indicate heat strain. The PHS and TWL indices are intended to predict the risk of heat disorders from climate conditions (ISO, 1995) and average metabolic work rate (ISO, 2004a), using predicted responses of the body such as sweating and elevated core temperature. To extend the usefulness of the indices, the thermal characteristics (i.e. insulation effect) of a variety of protective clothing combinations have been included in the calculation (Barker, Kini & Bernard, 1999). The indices assume that light clothing is worn (e.g. cotton clothing or cotton/polyester blends), and that the body responds similarly for all persons working under the same conditions. The WBGT index – with its simple calculation and quick result – was developed for ease of use in an industrial setting; it provides a compromise between a precise index and the need for a fast assessment. Therefore, it is best used to determine whether a problem exists by identifying whether reference values are exceeded. If this occurs, the more advanced PHS or TWL should be used to provide a more accurate estimation of heat stress (Bethea et al., 2002).

Widely used by the UK and European mining industry and by some underground mines in Australia, Basic Effective Temperature (BET) is a subjective thermal or empirically based index that combines dry bulb temperature, aspirated (psychometric) wet bulb temperature and air velocity, and is read from specially constructed nomograms. A code of practice for working in hot and humid conditions in coalmines has been developed, wherein BET limits are provided (Hanson & Graveling, 1997).

When using the WBGT, TWL or PHS indices as limiting values, the limits are only appropriate for workers who:

- Have been screened for intolerance to heat, are in good health and are fit for the activity being considered
- Have been properly instructed in the details of their work tasks and the potential effects and signs and symptoms of heat stress
- Are able to self pace their work
- Are under some degree of supervision (minimally a buddy system)
- Are not wearing clothing that restricts sweat evaporation or heat loss.

These indices should only be used as guidelines and not as safe/unsafe limits as no single index can accurately account for all the variables associated with heat stress assessment. Different thermal indices are suitable for different thermal and work conditions, and all have some limitations in terms of their ability to predict human response to the environment. The generalist OHS professional should be aware of these indices, their application and limitations and when specialist advice may be required as part of the assessment.

4.5.3 Level 3: Physiological monitoring

Where allowable exposure time determined by use of a rational heat stress index (e.g. PHS or TWL) is less than 30 minutes or there is a high level of personal protective equipment (PPE), there should be some form of physiological monitoring (ISO, 2001; Di Corleto, 1998). PPE clothing inhibits evaporation by producing a humid microclimate and diminishes the cooling effect of the evaporation that does take place (Nunnely, 1989).

Physiological monitoring is based on an individual's reactions to the thermal stress to which they are being exposed. These direct measurements take into account the variables (e.g. age, fitness) for which assumptions are made in the Level 2 assessment that utilises indices. Physiological assessment provides a more accurate result and a greater level of confidence as to the impact on the individual regardless of the conditions and, importantly, includes the impact of PPE.

Urine specific gravity

Hydration status can be assessed by measuring urine specific gravity (USG), which is "the mass of a urine sample compared with the mass of an equal volume of water" (Armstrong, 2003, p. 224). The US National Athletic Trainers' Association (NATA) recommended that: "Fluid replacement should approximate sweat and urine losses, and at least maintain hydration at less than 2% body weight reduction" (Casa et al., 2000). Also, NATA stated that a USG of greater than 1.020 would reflect dehydration as indicated in Table 1.

Table 1: National Athletic Trainers Association index of hydration status (adapted from Casa et al., 2000)

	Body Weight Loss (%)	Urine Specific Gravity
Well hydrated	<1	<1.010
Minimal dehydration	1 - 3	1.010 – 1.020
Significant dehydration	3 - 5	1.021 – 1.030
Severe dehydration	> 5	> 1.030

Research has confirmed that a USG of 1.020 is the most appropriate limit value indicating dehydration (Sawka et al., 2007; Cheuvront & Sawka, 2005). At this value, a body weight loss of 3% fluid or more would be expected. Generally, a loss of 2–3% body fluid is regarded as the level at which there is an increased perceived effort, increased risk of heat illness, and reduced physical and cognitive performance (Hunt, Stewart & Parker, 2009). There are several USG monitoring methods; while some organisations are utilising the convenient urine dipsticks for self-testing by employees, the more accurate and widespread testing method involves use of a refractometer, either electronic or optical hand-held.

Urine production and colour

The level of urine production decreases as dehydration increases; urine levels of less than approximately 250 mL produced twice daily indicate dehydration. Urine colour is a useful guide for tracking levels of dehydration (Armstrong et al., 1998). Colour intensifies as the urine concentrates with a dark yellow colour indicating severe dehydration through to a pale straw colour when hydrated. However, colour may be affected by some foods, illness, medications and vitamin supplements.

4.6 Legislation and standards

The national model *Work Health and Safety Regulations* (WHSR) (SWA, 2019) require that "a person conducting a business or undertaking (PCBU) must, so far as is reasonably practicable, ensure that: ...workers exposed to extremes of heat or cold at the workplace are able to carry out work without risk to health and safety" (WHSR s 40 (f).

Historically in Australia, the various legislative frameworks, federal and state, have not specifically regulated exposure levels for heat stress. For example, in New South Wales, the *Occupational Health and Safety Regulation 2011* (Government of NSW, 2017) require the general duty that "workers carrying out work in extremes of heat or cold are able to carry out work without risk to health and safety". Generally, all states provide guidance in the form of either compliance codes (e.g. WorkCover NSW; industry-specific guides; or guidance publications and newsletters). An exception is Queensland where the *Mining and Quarrying Safety and Health Regulation 2017 s 143* (Queensland Government, 2017a) refers to specific values:

1) The site senior executive must ensure the mine has a system for managing the risk to persons from heat in places at the mine where the wet bulb temperature exceeds 27°C.
2) The system must provide for setting maximum wet and dry bulb temperature limits for the persons' exposure having regard to subsection (3) and any criteria stated in a guideline for managing heat.
3) The site senior executive must ensure a person is not exposed to a wet bulb temperature exceeding 34°C at the mine unless the person is
    a) engaged in work to reduce the temperature… or
    b) a mines rescue member carrying out training or emergency response under procedures documented in the system; or
    c) being evacuated in an emergency.

Furthermore, under the equivalent Queensland coal mining regulation (Queensland Government, 2017b, regs 369-370), Division 2: Heat Stress Management, (Clause 369) also stipulates

1) "….must provide for ensuring the health of persons in places at the mine in which-
    a) The wet bulb temperature exceeds 27ºC

Furthermore, in Part 3) it goes on to say:

3) A person must not work in a place at the mine where the effective temperature exceeds 29.4°C……

In the UK mines, work tends to continue to an informal limit of 27ºC BET, when action to reduce risk of heat strain is particularly required. The Australian Institute of Occupational Hygienists' guide to managing heat stress (Di Corleto, et al., 2013) does not refer to specific environmental exposure limits.

Both the American Conference of Industrial Hygienists (ACGIH, 2018) and the International Organization for Standardization (ISO, 2004b) have published physiological limits. The ACGIH (2016) stipulated that exposure to environmentally or activity-induced heat stress must be discontinued in the following circumstances:

- Sustained (several minutes) heart rate in excess of 180 beats per minute (BPM) minus the individual's age in years (e.g. 180 – age), for individuals with assessed normal cardiac performance; or
- Body core temperature greater than 38.5°C for medically selected and acclimatised personnel; or greater than 38°C in unselected, unacclimatised workers; or
- A worker's recovery heart rate at one minute after a peak work effort is greater than 120 bpm, or
- There are symptoms of sudden and severe fatigue, nausea, dizziness, or lightheadedness.

An individual may be at greater risk of heat related disorders if:

- A worker experiences profuse and prolonged sweating over hours and may not be able to adequately replenish fluids; or
- In conditions of regular daily exposure to the stress, 24-hour urinary sodium excretion is less than 50 mmoles.

The ACGIHs overriding advice is to never ignore any signs or symptoms that may be apparent in relation to heat related exposures. *ISO 9886:2004 Ergonomics – Evaluation of Thermal Strain by Physiological Measurements* (ISO, 2004b) suggested that exposure to environmentally or activity-induced heat stress must also be discontinued when 'Heart Rate Limit = 185 – 0.65A' (where A = age in years) is reached. As individual variability can range up to 20 bpm from this average, this level could present a risk for some individuals. Where there is uncertainty, the sustained heart rate over a work period should not exceed a lower limit of $HRL_{,sustained}$ = 180 – age. No matter which limiting values are used, interpretation requires discussion with the workers affected and may require assessment by a specialist occupational hygienist especially where there are extended shifts.

4.7 Controls

Various factors must be addressed in managing and minimising the risk associated with working in hot environments; no one control will be effective. A range of controls is given below.

Elimination/substitution

- Work should be scheduled to avoid the hottest part of the day.
- Design of buildings housing hot processes should where possible incorporate good air flow through positioning of windows, shutters and roof design to encourage 'chimney effects' to help dissipate the heat from the structure.
- Reflective or light-coloured external cladding and roofing can reduce internal temperatures.

Engineering

- Air circulation should be sufficient to allow evaporation of sweat (the body's principal cooling mechanism). In high humidity more air needs to be moved, hence higher air velocity is required. This can be facilitated by fans. Caution should be exercised when increasing air movement in temperatures above approximately 40 - 45°C as at these temperatures the increased heat load may exceed the benefit obtained from sweat evaporation. In such cases, cooled air from 'chiller' units should be utilised where possible.
- Barriers may be useful where radiated heat from a process is a problem. Barriers may be highly reflective surfaces such as aluminised sheeting or even tarpaulins. Wherever practical, hot pipes or ductwork should be lagged or insulated to prevent the addition of heat to the work environment.

Administrative controls

- Ready access to cool palatable drinking water is a basic necessity.
- A clean cool area for employees to rest and recuperate may be important. Whilst resting in the work environment can provide some relief for the worker, the level of recovery is much quicker and more efficient in an air-conditioned environment. These need not be elaborate structures; basic inexpensive portable enclosed structures with an air conditioner, water supply and seating have been found to be successful in a variety of environments. For field teams with high mobility, even a simple shade structure readily available from hardware stores or large umbrellas can provide relief from solar radiation.
- Work-rest regimes are sometimes necessary where engineering controls are insufficient to protect the individual. Heat stress indices, such as WBGT, PHS or TWL (section 4.5), assist in determining duration of work and rest periods.
- Mechanising tasks to reduce the metabolic workload.
- Allow unacclimatised personnel time to acclimatise with light tasks allocated for the first few days in a job
- Training workers to identify symptoms and the potential onset of heat-related illness as part of the 'buddy system.'
- Self-determination or pacing of the work to meet the conditions.

Personal protective equipment

- PPE such as cooling vests with either 'phase change' cooling inserts (not ice) or vortex tube air cooling may be used in some situations, particularly when a cooling source is required when supplied air respirators are used. Ice or chilled water can result in contraction of the blood vessels, reducing the cooling effect of the garment, so tend not to be used.
- Clothing appropriate for the environment and task. For example, light and vented to allow air flow or in cases where radiant heat is an issue, with the use of a slightly heavier and/or reflective material to provide some insulation.

5 Understanding the impact of cold environments

While not as common as exposure to high temperatures in industrial situations in Australia, exposure to low temperatures does occur and can result in significant injury and illness if not properly addressed. Cold exposure can occur in cold-storage areas associated with the freezing of food products, in meat-processing plants, in low-temperature exterior climates (particularly in the elevated mountain regions in winter) and in extreme scenarios in other countries and Polar regions. For example, the coldest wind chill recorded in Canada was on January 13 1975 at Kugaaruk, Nunavut, where the air temperature was -51ºC with 56 km/hr winds, producing a wind chill of -78 (Environment Canada, 2019). Cold stress refers to endurance of low-temperature conditions sufficient in duration and intensity to result in an alteration or adaptation of internal systems (Reed et al., 2013). The exposure may be general, affecting the whole body, or localised involving only extremities or the face.

It is important to ensure that the core body temperature does not drop below 36ºC at which point shivering becomes uncontrollable, vasoconstriction occurs and the heart rate can decrease. In severe cases, prolonged low body temperatures can result in death. Three key components play major roles in the impact of cold environments on the individual:

- Low temperature
- Wind speed
- Wetness.

The varying combination of these factors can determine the severity of cold stress for the work environment (Figure 1).

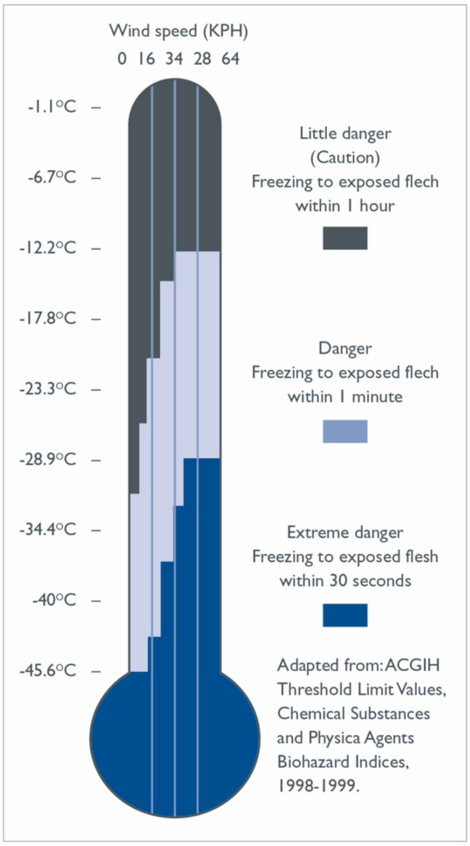

Figure 1: Combined effect of temperature and wind speed on cold stress (adapted from OSHA, 1998)

5.1 Health effects

The impact of exposure to cold environment can range from local damage to body parts (e.g. hands, face or feet) to general hypothermia from exposure to cold air and/or immersion risks in cold water. In *Best Practice – Working Safely in the Heat and Cold*, the Government of Alberta provided the following details about the health effects of cold exposure (Work Safe Alberta, 2012, p. 14):

> **Chilblains** are a mild cold injury caused by prolonged and repeated exposure for several hours to air temperatures from the freezing point (0°C) to as high as 16°C. Where the skin is affected, there will be redness, swelling, tingling, and pain.
>
> **Immersion foot** occurs in individuals whose feet have been wet, but not freezing cold, for days or weeks. It can occur at temperatures up to 10°C. The primary injury is to nerve and muscle tissue. Symptoms include tingling and numbness; itching, pain, swelling of the legs, feet, or hands; or blisters may develop. The skin may be red initially and turn to blue or purple as the injury progresses. In severe cases, gangrene may develop.
>
> **Trenchfoot (or hand)** is "wet cold disease" resulting from prolonged exposure in a damp or wet environment from the freezing point to about 10°C. Depending on the temperature, symptoms may begin within several hours to many days, but the average is three days.
>
> **Frostnip** is the mildest form of a freezing cold injury. It occurs when ear lobes, noses, cheeks, fingers, or toes are exposed to the cold and the top layers of the skin freeze. The skin of the affected area turns white and it may feel numb. The top layer of skin feels hard but the deeper tissue still feels normal (soft). The top layer of skin sometimes peels off the affected area.
>
> **Frostbite** is caused by exposure to extreme cold or by contact with extremely cold objects (e.g. metal). It may also occur at normal temperatures from contact with cooled or compressed gases. Frostbite occurs when tissue temperature falls below freezing (0°C), or when blood flow is obstructed under cold conditions. Blood vessels may be severely and permanently damaged, and blood circulation may stop in the affected tissue. In mild cases, the symptoms include inflammation (redness and swelling) of the skin in patches accompanied by slight pain. In severe cases, tissue damage without pain, or burning or prickling sensations and blistering can happen. Frostbitten skin is highly susceptible to infection, and gangrene (local death of soft tissues due to loss of blood supply) may develop.
>
> **Hypothermia** occurs when the body is unable to compensate for its heat loss and the body's core temperature starts to fall. You first feel cold followed by pain in exposed parts of the body. As the body's core temperature continues to drop, the feeling of cold and pain starts to diminish because of increasing numbness (loss of sensation). If no pain can be felt, serious injury can occur without the victim noticing it. As the body continues to cool, muscular weakness, an inability to think clearly, and drowsiness are experienced. This condition usually occurs when the body's internal or core temperature falls below 33°C. Additional symptoms include shivering coming to a stop, diminished consciousness and dilated pupils. When the core temperature reaches 27°C, coma (profound unconsciousness) sets in.

Hypothermia is a condition that results when the body's core temperature falls below 35°C. Warning signs can include nausea, fatigue, irritability or euphoria. An affected person may not fully realise the danger of the situation because the progressive cooling of the body can cause mental confusion and impaired judgement. If untreated, hypothermia may result in death (Weinberg, 1993). Alcohol should be avoided as it can cause a lowering of the blood sugar level and consequently rapid body cooling in an exhausted victim. (BOHS. 1996)

5.2 Legislation and standards

As with hot environments, the national model regulations (WHSR) (SWA, 2019) (s 40 (f)) require that "a person conducting a business or undertaking (PCBU) must, so far as is reasonably practicable, ensure that: ...workers exposed to extremes of heat or cold at the workplace are able to carry out work without risk to health and safety". Apart from that there is limited reference to work in cold environments in the regulatory space. Safe Work Australia provide a short piece in their Code of Practice *Managing the work environment and facilities* (SWA, 2015) which is also replicated by the NSW Government Code of Practice (NSW Government, 2019) of the same name.

The different state OHS regulators provide relevant codes and guidelines; for example, WorkSafe Victoria (2017) produced a handbook targeting cold storage facilities and a number of industry-specific guides and fact sheets provide practical and useful information.

5.3 Controls

Controls for working in cold climates tend to focus on administrative controls and PPE. Some examples of controls are listed below.

Elimination/substitution

- Warm air jets, radiant heaters and contact warm plates have been used in some situations.
- Where possible tasks should be undertaken in the warmest part of the day.

Engineering

- Tools with metal handles should be covered by thermal insulating material when used in sub-zero climates.

Administrative controls

- Appropriate training of employees in relation to cold exposure.
- Work/rest regimes in warm shelters can protect employees working in cold environments with an equivalent chill temperature below -7°C (BOHS, 1996).
- For work locations such as cold stores or where the temperature is below -12°C constant supervision such as the use of a 'buddy system' should be utilised.
- Work output should be controlled to minimise heavy sweating; where this cannot be avoided, individuals should be encouraged to take rest breaks to allow them to change into dry clothes.[6]

[6] For very low temperatures (below -26°C) refer to the work/warm up schedule in ACGIH (2010) adapted from the Occupational Health and Safety Division, Saskatchewan Department of Labour.

Personal protective equipment and increasing resistance

- Selection of suitable clothing that can be layered to adjust the changing environmental conditions; protection of extremities with hats and gloves.
- Cold injuries to the extremities are the most common problem in low temperature climates; where the tasks require manipulation or adjustment of fine components it is important to ensure that workers hands are protected and kept warm, but also that tactile senses are not impaired and task performance is not diminished.
- Drink warm, sweet beverages preferably caffeine free and avoid alcohol.
- Consume warm, high-calorie foods (e.g. pasta).

6 Contact injuries

Within the occupational environment there are numerous thermal sources (both hot and cold) that can result in discomfort or burns to the skin. For example, the national model regulations (SWA, 2019) specifically refer to:

> **Guarding and insulation from heat and cold**
> The person with management or control of plant at a workplace must ensure, so far as is reasonably practicable, that any pipe or other part of the plant associated with heat or cold is guarded or insulated so that the plant is without risks to the health and safety of any person. (WHSR s 209)

Thermal contact injuries may range from superficial burns that do not penetrate the outer layer of skin or epidermis, through partial-thickness burns that penetrate the outer layer but not the inner layer of skin or dermis to full-thickness burns that penetrate the skin and damage the underlying tissue below (Parsons, 2003) (see, for example, Figure 2)

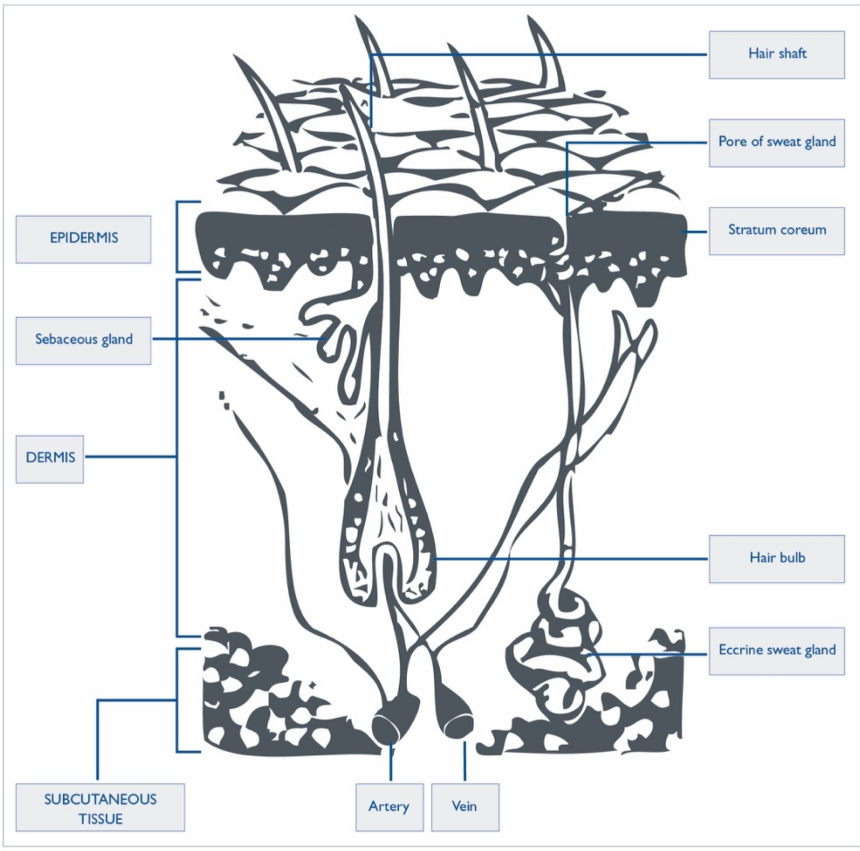

Figure 2: The structure of human skin

While the international standard *ISO 13732–1:2006 Ergonomics of the Thermal Environment – Methods for the Assessment of Human Responses to Contact with Surfaces – Part 1: Hot Surfaces* (ISO, 2006) provides a comprehensive risk-assessment process, a simplified version for contact burns when working with hot machinery is provided below.

1. Through consultation with the operator/s, identify contact points, touchable surfaces and length of contact periods.
2. Use task analysis and observation to determine worker behaviour under normal and extreme use of the machine.
3. Establish conditions that would produce maximum temperatures of touchable parts of the equipment (not normally heated as an integral part of the functioning of the machine).
4. Undertake surface temperature measurements while the machine is operating.
5. Determine the burn threshold value (i.e. the temperature which is the boundary between no burn and a superficial burn). Multiple thresholds may need to be utilised where different materials are involved.
6. Compare the measured results with the burn thresholds.

Also, there is potential for injury resulting from short or prolonged contact with cold surfaces. Curves of surface temperature and exposure time are provided for touching and gripping of cold surfaces for a variety of materials including aluminium, stone, nylon and steel in Youle and Parsons (2009) and in *ISO 13732–1:2005 Ergonomics of the Thermal Environment – Methods for the Assessment of Human Responses to Contact with Surfaces – Part 3: Cold Surfaces* (ISO, 2005).

7 Implications for OHS practice

In general, much of the assessment and determination of controls in relation to the thermal environment can be undertaken by the generalist OHS professional. Many of these controls are not complicated and are relatively easily implemented, in fact the simpler the better. In some cases there may be required a combination of controls from the different levels of the hierarchy of controls, i.e. engineering and administrative. It is also important to note that one of the key factors associated with the management of the thermal environment is a good understanding of the hazards, the controls available and the symptoms as they present early in the exposure. It is thus imperative that individuals potentially exposed be provided with the appropriate training.

There are some instances where the exposure may not have been adequately characterised, hence making the selection of controls more difficult or the exposures are so extreme that they are not easy to determine. In such situations the utilisation of professionals with experience in the monitoring and assessment of thermal environments such as occupational hygienists or others knowledgeable in the application of physiological monitoring and assessment such as occupational physicians or thermal physiologists should be approached to assist.

8 Summary

After brief consideration of the historical context and the extent of the problems associated with occupational exposure to extreme hot and cold environments, this chapter focused on provision of information about the thermal environment that is likely to be relevant to the generalist OHS professional role. It elucidated the health effects of hot and cold environments, addressed risk assessment and presented control options. Given the relevance of heat exposure to Australian working conditions, this information was supplemented with a three-tiered approach to the assessment of heat exposure. Finally, the implications for OHS practice were considered.

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Appendix 1: Basic Thermal Risk Assessment (informative only)

Reproduced from the Australian Institute of Occupational Hygienists' *A guide to managing heat stress: Developed for use in the Australian environment*. (Di Corleto, Firth & Matè, 2013)

HAZARD TYPE	Assessment Point Value			
	0	1	2	3
Sun Exposure	Indoors ❑	Full Shade ❑	Part Shade ❑	No Shade ❑
Hot surfaces	Neutral ❑	Warm on Contact ❑	Hot on contact ❑	Burn on contact ❑
Exposure period	< 30 min ❑	30 min – 1hour ❑	1 hour - 2 hours ❑	> 2 hrs ❑
Confined space	No ❑			Yes ❑
Task complexity		Simple ❑	Moderate ❑	Complex ❑
Climbing, up/down stairs or ladders	None ❑	Low ❑	Moderate ❑	Significant ❑
Distance from cool rest area	<10 Metres ❑	10 - 50 Metres ❑	50-100 Metres ❑	>100 Metres ❑
Distance from drinking water	<10 Metres ❑	10 - 30 Metres ❑	30-50 Metres ❑	>50 Metres ❑
Clothing (permeable)		Single layer (light) ❑	Single layer (mod) ❑	Multiple layer ❑
Understanding of heat strain risk	Training given ❑			No training given ❑
Air movement	Strong Wind ❑	Moderate Wind ❑	Light Wind ❑	No Wind ❑
Resp. protection (-ve pressure)	None ❑	Disposable Half Face ❑	Rubber Half Face ❑	Full Face ❑
Acclimatisation	Acclimatised ❑			Unacclimatised ❑
SUB-TOTAL A				
		2	4	6
Metabolic work rate*		Light ❑	Moderate ❑	Heavy ❑
SUB-TOTAL B				

		1	2	3	4
Apparent Temperature		< 27°C ❑	>27°C ≤ 33°C ❑	>33°C ≤ 41°C ❑	> 41°C ❑
SUB-TOTAL C					
TOTAL = A plus B	Multiplied by	C	=		

***Examples of Work Rate.**

Light work: Sitting or standing to control machines; hand and arm work assembly or sorting of light materials.

Moderate work: Sustained hand and arm work such as hammering, handling of moderately heavy materials.

Heavy work: Pick and shovel work, continuous axe work, carrying loads up stairs.

Instructions for use of the Basic Thermal Risk Assessment

- Mark each box according to the appropriate conditions.
- When complete add up using the value at the top of the appropriate column for each mark.
- Add the sub totals of Table A & Table B and multiply with the sub-total of Table C for the final result.
- If the total is **less than 28**, the risk due to thermal conditions is low to moderate.
- If the total is **28 to 60**, there is a potential of heat-induced illnesses occurring if the conditions are not addressed. Further analysis of heat stress risk is required.
- If the total **exceeds 60**, the onset of a heat-induced illness is very likely and action to implement controls should be taken as soon as possible.

It is important to note that that this assessment is to be used as a guide only. A number of factors are not included in this assessment, such as employee health condition and the use of high levels of PPE (particularly impermeable suits). In these circumstances experienced personnel should carry out a more extensive assessment..