Physical and Mental Health Challenges of Construction Workforce Active in Extreme Weather Conditions

by

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DEDICATION

In memory of my father

Late Karthick P, *Scientist-SG, IPRC, Department of Space*

Who has been a constant source of inspiration!

Who has been my strength!

Who I always admire and look up to!

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CHAPTER 1

INTRODUCTION

1.1. Background

Global warming has resulted in rising number of extreme hot and cold weather days. Impact of climate change has profoundly affected the economy of several countries (Field, C.B. et al., 2014). Immediate effects of climate change are not comprehensible; however, the effects of increasing summer and winter months clearly indicate the need to investigate the causalities. Heat wave warnings and cold winter spells are becoming more evident in recent years, hence gathering more attention on public health and safety (Budhathoki and Zander 2019). Extreme temperatures have led to rising number of mortality rates and morbid conditions every year (Gronlund et al., 2019; Karthick et al., 2021). General public health and more specifically outdoor working population are more affected in extreme hot and cold weather conditions (Hanna et al., 2011).

Exposure to extreme temperatures affects construction workers health in various ways. Construction work sites are hazardous to workers in very hot days when temperatures soar beyond unbearable limits, putting workers at the risk of heat stress (Kiefer et al., 2016). Similarly, when workers are performing physically demanding activities in cold weather, they are at the risk of cold stress (Angelova 2017). Increase in hospitalizations and emergency department visits are more common for heat and cold related worker injuries. When outdoor workers work in uncontrolled temperatures, they are at risk of compromised worker safety resulting increased accidents and occupational injuries in workplaces (Varghese et al., 2018; Namian et al., 2022).

Workers performing in hot weather conditions are at risk of developing physical challenges such as heat cramps, heat edema, heat exhaustion, heat stroke, kidney diseases and mental health issues like anxiety, depression, and distraction from work (Acharya et al., 2018). When performing in cold weather, workers might be at risk of developing health conditions like frostbite, respiratory issues, musculoskeletal disorders, cardiological problems and mental challenges like inability to concentrate, mental fatigue, impaired cognition (Angelova 2017; Rouhanizadeh and Kermanshachi 2021). Several studies are focused on the public health effects of extreme temperatures, however, only very few studies explored the effects of extreme temperatures on construction workers health. Therefore, this study identifies the various health challenges experienced by construction workers and classifies them into physical and mental health categories and provides strategies to ensure construction workers health and safety in extreme weather conditions.

1.2. Problem statement

Recent rise in heat waves and cold spells have gathered researchers attention to focus on health conditions and vulnerabilities. Outdoor workers are majorly affected by extreme hot and cold weather conditions. Demographic characteristics of individuals play a major role in determining health susceptibilities. Certain group of population is more vulnerable to the effects of heat and cold based on factors such as age, gender, ethnicity, habits, and co-morbidities (Acharya et al., 2018; Pamidimukkala and Kermanshachi 2022c). Therefore, individuals who are vulnerable to extreme temperatures in construction sectors need to be specifically identified to develop unique strategies and managerial recommendations. Several literature studies focusing on the health consequences of hot weather conditions are available, however, only very few literature studies are available for cold weather conditions (Sugg et al., 2019). The legal body, Occupational Health and Safety Administration (OSHA) provide standards and policies governing workers safety. Despite the increasing number of accidents, injuries, hospitalizations and mortalities due to rising number of hot weather conditions, OSHA provides a general clause where employers are held responsible for worker safety, rather than specific guidelines to safeguard workers from hot weather conditions (Arbury et al., 2016). However, employers in construction sites lack efficient systems that allows to continuously monitor workers health when performing in extreme temperatures. Similarly, construction workers performing in cold weather do not have specific regulations other than a generalized clause which states on creating a hazard free workplace. These circumstances can be improved when sufficient studies are evidently available to highlight the importance of health challenges experienced by workers in construction sector due to working in extreme hot, cold temperatures and practically implementable solutions are made. Considering the above deficiencies, a study focusing on analyzing and modelling workers health in extreme hot and cold weather condition in construction sector is required.

1.3. Research objective

The objectives of this research are formulated as follows:

(1) To identify the various physical and mental health challenges experienced by construction workers when working in extreme weather conditions through a thorough literature study and questionnaire survey.

(2) To identify the significant physical and mental health challenges based on demographic characteristics, physiological indicators, and personal indicators.

(3) To develop an explanatory model using logistic regression to identify the impact of hot weather on workers' occupational fatigue, accidents and respiratory health based on various socio-demographic attributes of the exposed individuals.

(4) To develop an explanatory model using logistic regression to identify the relationship between cold weather conditions and respiratory health problems in construction workers when performing physically demanding activities in extreme cold conditions.

1.4. Dissertation outline

Chapter 1 includes the background of research, problem statement of the research, and outlines the research objectives. Chapter 2 presents an article that systematically outlines the overview of various physical and mental health challenges experienced by construction workers in hot and cold weather conditions. Several managerial recommendations and strategies in the order of hierarchy of controls were presented based on a systematic review. Chapter 3 presents the results of descriptive analysis of the healthcare costs incurred by construction workers when performing in extreme hot and cold weather conditions based on various demographic attributes. Chapter 4 presents an article that analyzes the workers' health challenges in hot weather conditions based on various physiological and personal indicators. The article also outlines the various standards from several geographical locations that experience soaring temperatures. Chapter 5 presents the findings on the significance of the various hot weather health challenges in terms of workers' drinking habits, perspiration, and their work environment. Chapter 6 presents a paper that analyzes the workers' health challenges in extreme cold temperatures based on physiological and personal indicators. Chapter 7 presents an article based on logistic regression model that explores the workers' physical fatigue and injuries in hot weather conditions based on socio-demographic characteristics of exposed workers. Chapter 8 presents a model based on logistic regression that explores the workers' respiratory health issues and freezing of exposed body parts in cold weather conditions based on socio-demographic characteristics of the exposed individuals. Chapter 9 summarizes this study and presents few of the limitations governing the outcomes of this study. The chapter also provides some of the possibilities and ideas for expanding the study in the future.

CHAPTER 2

A REVIEW OF CONSTRUCTION WORKFORCE HEALTH CHALLENGES AND STRATEGIES IN EXTREME WEATHER CONDITIONS

2.1. Abstract

Construction sites continue to operate despite inclement weather, exposing workers to unpleasant working circumstances that can lead to various physical and mental health challenges. A thorough literature review yielded 21 challenges for hot weather conditions such as heat stroke, kidney disease, heat cramps, anxiety, depression and 20 challenges for cold weather conditions like asthma, frostbite, Musculo-Skeletal disorders, hallucination. Workers vulnerable to hot and cold weather based on demographic characteristics were identified. The study also provides 27 strategies to address the challenges experienced in hot and cold weather conditions. Some of these include ensuring that workers stay hydrated, scheduling sufficient rest periods, and allowing workers to self-pace. The results of this study will help construction decision-makers and project managers understand the difficulties faced by a field workforce who labors in extreme working conditions on construction sites and will facilitate adoption of strategies that can prevent weather-related physical and mental health problems.

Keywords: Construction workers, Extreme weather, Worker health, Worker safety, Health challenges.

2.2. Introduction

Construction workers and laborers play a crucial role in the completion of projects. They often work in an unprotected environment, where they are exposed to extreme hot and/or cold temperatures, and high winds. These unfavorable conditions make the workers less productive and pose risks to their health and safety. According to bureau of labor statistics (BLS), 907 workers were killed due to exposure to environmental heat stress during the period 1992 – 2019 (BLS 2019). An average of 3507 heat related injuries and illnesses occurred per year during the period 2011 – 2019 (BLS 2021). An average of 1706 cold related occupational injuries occurred during the year 2017 (BLS 2017). Therefore, the health challenges that they face need to be identified and addressed in order to protect their health and reduce the number of accidents on construction sites. Human physiology encompasses both physiological and behavioral responses that sustain a reasonable core body temperature (CBT) that ranges from 35 to 40 °C (95° to 104 °F) despite being exposed to a broad range of ambient temperatures. Thermoregulation is the body's ability to maintain and adjust its internal temperature. When it is unable to do so, thermal stress causes a series of short- and long-term health concerns (Cheung et al., 2016). Therefore, when outdoor workers are exposed to extreme heat or cold and their system is unable to thermoregulate, they experience heat or cold stress that renders them susceptible to various illnesses such as musculoskeletal disorders, cardiovascular strain, kidney disease, etc. (Cheung et al., 2016; Renberg et al., 2020). Factors such as acclimatization, individual heat/cold tolerance levels, water intake capacity, and body mass index also affect the extent to which workers are impacted. These factors are interrelated and should be considered while evaluating heat- or cold-related stress (Kemala et al., 2018). Water intake capacity refers to the amount of fluid consumed by an individual and the frequency with which it is consumed. Workers who drink more fluids are less affected by extreme heat than those who drink less (Kemala et al., 2016); therefore, it is recommended that those who work outdoors in hot weather drink more than the minimum daily requirement of fluids to avoid related health issues. The amount of water needed by an individual varies according to factors such as age, weight, the intensity of physical work, and the temperature, but drinking more water to stay hydrated is always suggested in extremely hot weather (Sawka et al., 2005).

The primary and overreaching responsibility of employers in any industry is protecting the safety and health of its workers, and this is especially true of the construction arena. Adequate occupational safety and health practices facilitate worker safety (Karthick et al., 2022d), reduce the number and extent of on-site accidents and property and equipment damage, and enable project productivity (Zahoor et al., 2016; Subramanya et al., 2022). The increasing number of worker compensation claims is one of the indicators that workers are affected by heat stress. Higher safety standards should be developed and implemented to ensure the health of the workers (Zahoor et al., 2016; Subramanya et al., 2022) and older workers should be given special consideration. Therefore, the objectives of this paper are to: (1) identify the various physical and mental health challenges experienced by construction workers in extremely hot and cold environments, (2) identify the group(s) of workers most vulnerable to extreme weather conditions, and (3) establish strategies to overcome the health challenges.

2.3. Methodology

A thorough literature search was conducted to identify the health and occupational challenges faced by construction workers in extreme weather conditions. Key words such as hot weather; cold weather; vulnerable workers; worker safety; construction workers' health; extreme weather; construction sites; accidents; mortalities; workplace regulations; strategies; and physical, mental, and emotional challenges were entered in different combinations into online search engines such as Google Scholar, Scopus, Science Direct, PubMed, Directory of Open Access Journals (DOAJ), ProQuest and Springer and yielded 167 journal articles and conference papers. Studies that discussed major health challenges resulting from being exposed to extreme hot and cold temperatures were also considered, whether or not they pertained specifically to the construction industry, as human physiological effects are relatable regardless of the type of occupation. In the second step, groups of workers vulnerable to health challenges caused by hot weather conditions were identified by their age, gender, level of acclimatization to local weather, and body mass index (BMI), but little data was available for workers who are vulnerable to health challenges caused by cold weather conditions. In the third step, the identified challenges were classified into two groups: those that resulted from exposure to hot weather and those that resulted from exposure to cold weather conditions. In the next step, strategies for mitigating the challenges were identified from the existing literature and were rated according to the hierarchy of controls from most effective to least effective. Figure 2.1. depicts the methodology of the literature search.

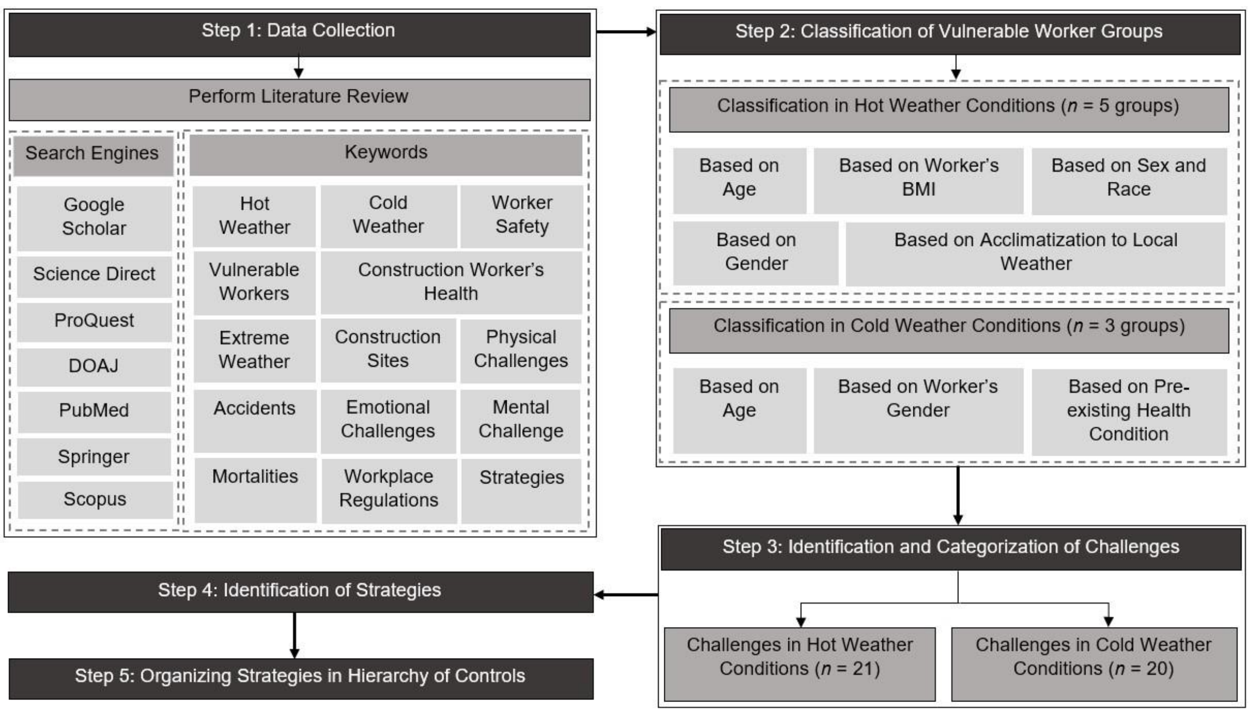


Figure 2. 1. Research Methodology

The inclusion and exclusion criteria followed a four-step process. First, 260 journal articles and conference papers were retrieved from the database by initiating a keyword search. Second, the records were screened to remove duplicates, which reduced the number of articles and conference papers to 245. Third, records that were published prior to the year 2000 were excluded, as they were cited in later publications. Fourth, the records were screened by title, and those considered irrelevant based on title were excluded. Fifth, the abstracts and full texts of journal articles and conference papers were studied and resulted in narrowing the list of relevant records to 167. The inclusion and exclusion criteria and screening process are briefly demonstrated in Figure 2.2.

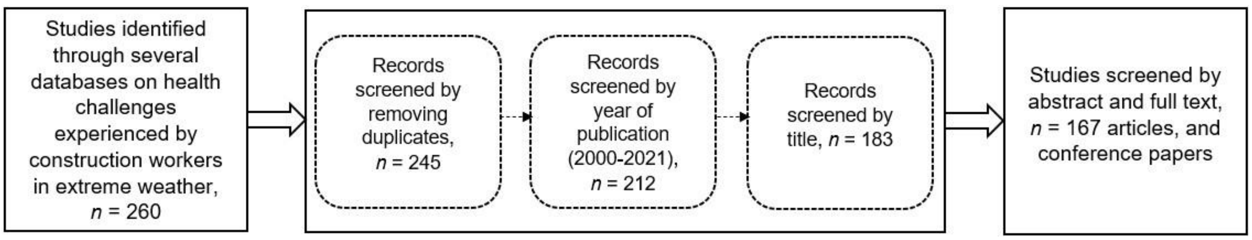


Figure 2. 2. Screening Process

2.3.1. Data Collection

As presented in Figure 2.2, the screening process of abstracts and full texts yielded 104 relevant articles, most of which were published in Safety and Health at Work, and Automation in Construction. The following table (Table 1) reveals the distribution of the existing publications.

Table 2. 1. Distribution and frequency of published journals

Journal	Frequency	Percentage
Safety and Health at Work	15	14%
Automation in Construction	13	13%
Industrial Health	8	8%
International Journal of Environmental Research and Public Health	7	7%
International Journal of Occupational Safety and Ergonomics	5	5%
Maturitas	5	5%
International Journal of Biometeorology	5	5%
International Journal of Circumpolar Health	4	4%
IEEE sensors journal	4	4%
Journal of Construction Engineering and Management	3	3%
Building and Environment	3	3%

Environment International	3	3%
International Journal of Industrial Ergonomics	3	3%
Global Health Action	2	2%
Applied Ergonomics	2	2%
Engineering, Construction and Architectural Management	2	2%
Occupational and environmental medicine	2	2%
Global health action	2	2%
Indian Journal of occupational medicine	2	2%
American Journal of Industrial Medicine	2	2%
Other*	12	12%
Total	104	100%

*Journals with frequency of one, such as occupational health.

The safety and health challenges faced by workers were not given much consideration in the early 2000's, but the increasing prevalence of extreme weather conditions has gathered much attention in the recent years which could possibly be justified due to the rising concern on extreme weather days. Those who work outdoors face more challenges than ever before, which behooves employers to establish a safe workplace that protects the health of their employees and has the added benefit of improving their productivity. The graph in Figure 2.3. shows that the high number of journal articles relevant to this issue that were published in recent years (2016 - 2020) is increasing, indicating that this is an area that is receiving increased focus.

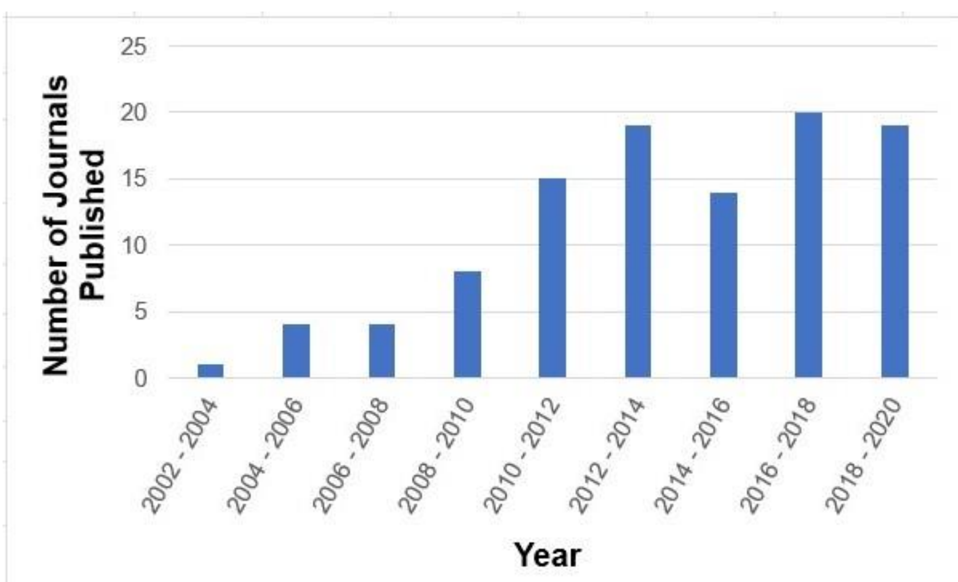


Figure 2. 3. Distribution of journals

2.4. Population Vulnerable to Hot Weather Conditions

Construction workers above 55 years of age are more vulnerable to weather-related stress than workers of other age groups (Rameezdan and Elmualim 2017). In countries where children work as laborers, it has been observed that children are highly susceptible to heat-related illnesses and death. Their thermoregulatory system experience a very high blood flow resulting in dehydration and heat-related disorders (Lundgren et al., 2013). Female construction workers are more affected than males (Gong et al., 2011; Rameezdan and Elmualim 2017), and pregnancy makes them even more vulnerable (Rahman et al., 207).

Race was not identified as a factor contributing to heat stress in the construction industry, even though it has been identified as such in other industries. Hispanic males and females have been observed to experience more heat-related disorders than non-Hispanic males and females (Acharya et al., 2018). Expatriates who work in outdoor extreme conditions suffer more heat stress and need to be observed more closely, as they have not been acclimatized (Wong et al., 2019). Based on workers' Body Mass Index (BMI), those who are underweight or obese have a higher rate of heat disorders than those who are of a healthy weight (Wong et al., 2018). Table 2 depicts the groups of workers who are most vulnerable to heat stress.

Table 2. 2. Identification of groups of workers most vulnerable to heat stress

ID	**Classification of vulnerable worker groups to heat stress**	**Identified vulnerable worker groups**	**Sources**
1.	Age (workers under 24, 25 – 34, 35 – 54, and above 55 years of age)	Workers over 55 years of age	Rameezdan and Elmualim 2017
2.	Gender (male workers, female workers)	Female workers and pregnant women	Gong et al., 2011; Rameezdan and Elmualim 2017
3.	Sex and race (non-Hispanic white men, Hispanic men)	Hispanic men and Native American men	Acharya et al., 2018

4.	Acclimatization to local weather (acclimatized workers, unacclimatized workers)	Expatriate workers	Lundgren et al., 2013; Xiang et al., 2014
5.	Worker’s BMI (underweight, normal weight, overweight, and obese workers)	Underweight and obese workers	Acharya et al., 2018
6.	Type of work (scaffolder, steel fixer, form worker, electrician, plumber, concreter, bar bender, bar fixer)	Bar benders, bar fixers, scaffolders, steel fixers, form workers	Lundgren et al., 2013

Note: BMI = body mass index

Workers performing activities at heights in extremely hot temperatures undergo psychological challenges, as well as physical challenges. Such challenges are faced by scaffolders, steel fixers, form workers, electricians, plumbers, and concrete workers (Chang et al., 2009). Wong et al (2014), mentioned that bar benders and bar fixers are at high risk of heat-related illnesses, as they have to work in confined spaces on top floors of buildings.

2.5. Challenges in Hot Weather Conditions

2.5.1 Physical Health Challenges

The effects of climate change, such as extreme weather events, high ambient temperatures, and increased air pollution, impact the safety and health of workers on construction sites (Lundgren et al., 2013). The maximum thresholds for environmental temperatures at which individuals can safely work are not yet enforced, as they are based on a multitude of parameters such as humidity, wind velocity, etc.; however, a heat index of 29.4 °C (84.92 °F) can be used as a benchmark to protect individuals from heat-related illnesses (Tustin et al., 2018). Levels of heat tolerance vary among individuals (Lundgren et al., 2013), as do their core body temperature and their body’s ability to thermoregulate. As mentioned earlier, the CBT is not constant, as it varies between 35° and 40 °C (95° to 104 °F). It is dependent upon exposure to extreme weather conditions and is affected by age, gender, and body mass, but in a worker who has been acclimated to working in extreme heat, it may reach 41.5 °C (106.7 °F) (Périard et al., 2021). The body’s inability to thermoregulate results in various physiological consequences like excessive sweating, a rapid heart rate, and dehydration (Lundgren et al., 2013). The various hot weather physical health challenges identified from the literature are summarized in the Table 3 below. Outdoor workers often experience heat strokes (HP1) and profound physical fatigue (HP2) when they perform physically demanding activities in extreme heat (Ma et al., 2019), and workers who labor indoors without inadequate ventilation and cooling systems also face severe health consequences (Schulte and Chun 2009).

Sultana et al. (2015), explored health problems faced by women working on construction sites in extremely hot temperatures and found that they exhibited several forms of dermatitis: heat rash (HP3), redness, and itchy skin. Hot weather also increases the incidence of injuries and accidents that can result in burns, wounds, and even amputations (HP4) (Xiang et al., 2014). Some of the health problems caused by working in hot weather include heat cramps, edema, and chronic kidney disease (Acharya et al., 2018). Heat cramps (HP5) are usually experienced by workers who sweat less after performing heavy manual work and who don't have enough electrolytes in the bodies; they usually occur when the worker is at rest, after working. Heat edema (HP6) develops in workers who stand for long periods of time (Ma et al., 2019; Périard et al., 2021; Karthick et al., 2022f) and heat strokes and exposure to high temperatures make workers four times as susceptible to chronic kidney disease (HP7) (Tseng et al., 2020). Table 3 shows the physical challenges that workers endure while working in extremely hot weather.

Table 2. 3. List of Physical Health Challenges Faced by Those Working in Hot Weather Conditions

ID	Physical Health Challenges	Causes	Symptoms	Sources
HP1	Heat stroke	Very high core body temperature	Seizures, agitation	Grubenhoff et al., 2007; Schulte et al., 2009; Wong et

				al., 2014; Ma et al., 2019
HP2	Physical fatigue and discomfort	Continuous strenuous activity	Dizziness, lightheadedness	Ma et al., 2019
HP3	Increase in accidents that result in amputation, burns, and wounds	Heat stress	Dizziness	Rameezdan and Elmualim 2017; Karthick et al., 2022h
HP4	Heat cramps	Depletion of electrolytes	Heavy sweating, fatigue	Grubenhoff et al., 2007; Xiang et al., 2014; Tusting et al., 2018
HP5	Heat edema	Accumulation of fluids in extremities	Swelling of legs or arms	Xiang et al., 2014; Johnson et al., 2019; Tustin et al., 2021
HP6	Chronic kidney disease	Inadequate hydration habits, repeated exposure to heat	Insufficient urine production	Yabuki et al., 2013; Xiang et al., 2014; Périard et al., 2021
HP7	Hypertension	Inadequate resting frequency, reduced water intake	Heart failure, stroke	Gauer and Meyers 2019; Umar and Egbu 2020
HP8	Heat rash and skin problems	Clogged sweat pores	Skin blisters, red rashes	Chang et al., 2009; Sultana et al., 2015; Gauer and Meyers 2019.
HP9	Cardiovascular strain	Increased cardiovascular function	Heart failure	Grubenhoff et al., 2007; Cheung et al., 2016; Leiva et al., 2022
HP10	Respiratory problems such as asthma, chronic lung disease	Air pollution, breathing hot air	Shortness of breath	Morioka et al., 2006; Johson et al., 2019
HP11	Dehydration	Reduced fluid consumption	Dizziness, low blood pressure	Rodahl 2003; Morioka et al., 2006; Wu et al., 2019

Note: HP = physical health challenges in hot weather conditions.

Those who regularly work outdoors in extreme heat are subject to hypertension (HP8), cardiovascular problems (HP9), and pulmonary issues, which, if undetected and untreated, can even result in death (Wu et al., 2019). In addition, high temperatures and relatively low humidity can create dust, which, along with winds, can cause respiratory health issues (HP10) like chronic lung disease, asthma, and silicosis (Alshebani et al., 2014). Workers in hot environments often become dehydrated (HP11) as a result of not drinking enough water or similar fluids (Bates and Schneider 2008).

2.5.2. Mental Health Challenges

The mental health challenges experienced by workers are summarized in Table 4 below and include depression (HM1) and suicide (HM2) (Al-Maskari et al., 2011). Al-Maskari et al. (2011), believed that suicide rates are higher among construction workers, especially males, because they are at higher risk of depression. Bates and Schneider (2008) found through intellectual tests that when a person is 2% dehydrated, their mental ability decreases, prolonged dehydration results in a decline in cognitive ability. When mental performance decreases, the number of accidents in the workplace increase due to the workers' irritation (HM3), anger (HM4), and other emotional states that are triggered by the uncomfortable environment (Bates and Schneider 2008; Sultana et al., 2015). Thus, Rodahl (2003) espoused that workers' thermal environment should be taken into consideration while evaluating their productivity. The ability to tolerate heat stress depends on individuals' behavioral characteristics also (Lundgren et al., 2013). A study that was conducted to find a relationship between physiological and perceptual responses to heat and sleep deprivation revealed that individuals who are sleep-deprived exhibit more symptoms of heat illnesses (Relf et al., 2018). They may suffer from central fatigue (HM5) and anxiety (HM6), resulting in reduced levels of perception (HM7) (Bates and Schneider 2008); and an inability to focus (HM8) (Gauer and Meyers 2019; Wu et al., 2019). Table 4 depicts the mental challenges faced by workers in extremely hot weather conditions.

Table 2. 4. List of Mental Health Challenges Faced by Those Working in Extreme Hot Weather Conditions

ID	Mental Health Challenges	Workplace Effects	Sources
HM1	Increased irritation	Increase in workplace conflicts	Schulte and Chun 2009
HM2	Anger	Negative coworker relation	Schulte and Chun 2009
HM3	Distraction from work	Increase in accidents	Schulte and Chun 2009
HM4	Central fatigue	Errors on work output	El-Shafei et al., 2018
HM5	Anxiety	Reduced job performance	Gauer and Meyers 2019; Wu et al., 2019
HM6	Reduced perception levels	Reduced decision- making ability	Bates and Schneider 2008
HM7	Emotional stress	Low worker morale	Crandall and González-Alonso 2010; Wu et al., 2019; Ebi et al., 2021
HM8	Confusion	Inability to make judgements	Yi et al., 2016
HM9	Depression	Absenteeism in workplace	Al-Maskari et al., 2011
HM10	Increased suicidal rates	Decrease in number of workers in construction industry	Al-Maskari et al., 2011

Note: HM = mental health challenges in hot weather conditions.

Performing physically laborious and mentally exhausting tasks in extremely hot temperatures can also induce mental fatigue. Construction workers in the desert of Saudi Arabi report psychological and physiological challenges that were caused by the extremely hot climatic conditions (Al-Bouwarthan et al., 2019) . Physical exhaustion leads to confusion (HM9) and emotional stress (HM10) (Yi et al., 2016), and when coupled with other factors, such as working in a location that is far from families and friends, can result in mental fatigue (Bates and Schneider 2008).

2.6. Population Vulnerable to Cold Weather Conditions

Exposure to extreme weather conditions is not uniform across the population, nor are individuals' reactions to cold. Demographic characteristics such as age, gender, and ethnicity have a considerable impact, as do pre-existing health issues. Older individuals are more susceptible to health issues stemming from exposure to cold weather, as their thermoregulatory mechanism is slower than that of other age groups, and pre-existing health conditions may prevent some individuals from recognizing how they are affected by the cold. This is because their blood pressure, rate of sweating, or use of medications may act as an obstacle to symptoms. The mortality rates for women, especially those over 65 years of age, are higher than for men; however, the relationship between mortality rates were not consistent, as other evidence indicates that younger individuals are more vulnerable than other age groups to cardiovascular deaths resulting from exposure to cold weather. Cold weather mortalities also vary based on geographical location and the intensity of the temperature. The United States, Korea, Brazil, Europe and Taiwan report increased deaths in cold temperatures, asserting the global importance of cold weather challenges faced by their populations. Those who live and/or work in cold regions should become familiar with the dangers that exposure can present, as there is evidence of higher incidences of weather-related death in such regions (Conlon et al., 2011).

2.7. Challenges in Cold Weather Conditions

2.7.1. Physical Health Challenges

International standards for workers define “cold” as temperatures at or below 10° to 15° C (Ikäheimo and Hassi 2011). The physical challenges experienced by those who work in cold temperatures were identified through the literature review, are summarized in Table 5, and are expanded upon in this paragraph. When the human body is exposed to cold, its internal temperature automatically falls, resulting in exposed parts becoming numb (CP1) and an increased number of accidents (CP2) (Grubenhoff et al., 2007; Al-Maskari et al., 2011). To prevent this, workers need to wear well-fitted personal protective clothing (PPC) that can entrap and retain heat. A proper fit is key to success, as clothing that is too loose does not retain warmth, and clothing that is too tight causes discomfort and a hobbling effect (CP3) (Renberg et al., 2020; Adepu et al., 2022; Pamidimukkala and Kermanshachi 2022b). When an individual’s body is unable to thermoregulate because of exposure to extreme cold, it's internal temperature falls and it exhibits cold-related illnesses that result in cold stress, slowed actions and reactions, and an inability to perform tasks at the normal level of competence causing physical fatigue (CP4) (Rodahl 2003). Hypothermia (CP5), which can decrease job performance by as much as 70% (Relf et al., 2019; Rouhanizadeh et al., 2021). and increases an individual's vulnerability to frostbite, necrosis, and respiratory problems, also occurs when the core body temperature falls significantly. Shivering from the cold, vasoconstriction of blood vessels (CP6) (Rodahl 2003). Exposure to cold leads to shivering and vasoconstriction of blood vessels (CP6) (Rodahl 2003), and cold injuries like frostbite (CP7) are due to tissue freezing as ice crystals form on exposed body parts (Al-Maskari et al., 2011; Conlon et al., 2011; Yi et al., 2016; Al-Bouwarthan et al., 2019). Frostbite and skin problems like dryness, pain, itching, and swelling are outcomes of exposure to cold dry air (Rodahl 2003). Workers exposed to rapid cooling are at risk of necrosis (CP8) (Conlon et al., 2011; Al-Bouwarthan et al., 2019).

Extreme cold also affects workers' respiration and causes problems in both their upper and lower respiratory tracts (CP9) (Rodahl 2003). It can also worsen pre-existing health issues, such as cardiovascular disorders, asthma, bronchitis and other respiratory problems (Sugg et al., 2019), and can cause extensive musculoskeletal problems, including pain and inflammation in the neck and lower back (CP10). When a worker's muscle temperature falls, the neuro muscular function is also reduced, which leads to an increased number of injuries and fatalities. Working in extreme cold weather also causes cardiovascular problems like myocardial infarctions, and prolonged exposure can result in hypertension (Rodahl 2003).

A major increase (15%) in emergency room visits by workers for cold-related injuries such as slips and falls (CP11) has been observed with every degree that the temperature falls during cold weather, and an increase in wind speed further increases the number of visits by 6% (Castellani et al., 2010; Adepu et al., 2022; Pamidimukkala and Kermanshachi 2022c). The rising number of slips, trips and fall-related accidents are attributed to ice, snow, limited visibility, and cooling of the body (Crandall and González-Alonso 2010). Two-thirds of all fall events in cold weather occur on ice that is coated with snow (Mäkinen and Hassi 2009). Trench foot or immersion foot are also the effects of working in cold environments (Kanerva et al., 2013; Rakhmanov et al., 2018). Trench foot (CP12) is a condition in which blood vessels are inflamed to the extent that they damage organs and tissues; it is common among those who work for prolonged periods of time in temperatures that are above 0° Celsius (32° Fahrenheit). Immersion foot develops when workers stand in the same position for long periods of time, especially in cold, wet environments (Angelova 2017). The terms trench foot and immersion foot are often used interchangeably; immersion foot, formerly known as trench foot, is considered a non-freezing cold injury. It is experienced by many outdoor workers, and often occurs when construction workers perform jobs, such as excavating a hole for a foundation, in cold, muddy water (Kanerva et al., 2013). The symptoms of immersion foot begin with numbness and white or pale skin that changes to a shade of blue. It is often characterized by numbness and severe pain, even after heat has been restored (Rathjen et al., 2019). Table 5 depicts the physical challenges and health issues that workers encounter in extremely cold temperatures.

Table 2. 5. List of Physical Health Challenges Workers Face in Cold Weather Conditions

ID	Physical Health Challenges	Causes	Symptoms	Sources
CP1	Numbness in exposed body parts	Exposed extremeties in cold	Increased nerve pain	Grubenhoff et al., 2007; Al-Maskari et al., 2011; Morabito et al., 2014

CP2	Increase in number of injuries	Continuous exertion in cold weather	Tiredness	Grubenhoff et al., 2007; Yi et al., 2016; Whitaker et al., 2016
CP3	Hobbling effect and uneasiness	Tight thermal clothing	Reduced ability to move	Grubenhoff et al., 2007; Bonafede et al., 2016; enberg et al., 2020)
CP4	Physical fatigue	Performing for longer duration in cold weather	Tiredness	Rodahl 2003
CP5	Hypothermia	Exececssive loss of heat	Weak pulse, lack of consciousness	Mäkinen and Hassi 2009; Relf et al., 2018; Lee et al., 2019
CP6	Vasoconstriction of blood vessels	Prolonged exposure to cold	Increase in blood pressure	Grubenhoff 2007; Mäkinen and Hassi 2009
CP7	Frostbite	Freezing of tissues	Long term numbness in affected region	Grubenhoff et al., 2007; Al-Maskari et al., 2011; Conlon et al., 2011; Yi et al., 2016; Al-Bouwarthan et al., 2019
CP8	Necrosis	Lack of blood supply to tissue	Malfunctioning of cells	Grubenhoff et al., 2007; Conlon et al., 2011; Al-Bouwarthan et al., 2019
CP9	Upper and lower respiratory issues	Inhaling cold, dry air	Shortness of breath	Grubenhoff et al., 2007; Ikäheimo and Hassi 2011; Tiwary and Gangopadhyay 2011
CP10	Musculoskeletal disorders like wrist, neck, back, and all over body pain and inflammation	Increased muscular load	Carpal Tunnel Syndrome	Castellani et al., 2010; Renberg et al., 2020

CP11	Increase in number of accidents caused by slips and falls	Icy and slippery surfaces in workplace	Major and minor injuries in body parts	Castellani et al., 2010
CP12	Trench foot	Performing activities in cold water	Blisters, blotchy skin	Whitaker et al., 2016; Fallahi et al., 2017; Sugg et al., 2019
CP13	Increase in onset of fatigue due to PPC	Increase in metabolic energy	Tiredness, weakness in muscles	Renberg et al., 2020
CP14	Reduced dexterity	Impaired response from hand receptors	Inability to handle tools and equipment	Relf et al., 2018; Angelova et al., 2017; Lee et al., 2019

Note: CP = physical health challenges in cold weather conditions; PPC = personal protective clothing.

The type of personal protective equipment (PPE) worn by workers affects the amount of metabolic energy that is expended, and the weight and height of safety boots are one of the few factors that contribute to a loss of metabolic energy thereby reducing the efficiency of the worker and increasing the onset of fatigue (CP13) and injuries (Renberg et al., 2020). Workers wearing PPE are less coordinated and have reduced dexterity (CP14) (Tiwary and Gangopadhyay 2011; Martinez-Solanas et al., 2018; Ray et al., 2018) and those who perform repetitive tasks might experience muscle overload that could lead to muscle damage (Burström et al., 2013). It has also been observed that workers in cold weather lack coordination in fingers leading to finger dexterity (Ray et al., 2018).

2.7.2. Mental Health Challenges

Exposure to cold weather leads to psychological stress (CM4) (Leon et al., 2011; Tiwary and Gangopadhyay 2011) and those who work in those conditions for prolonged periods of time are at risk of hypothermia (Castellani et al., 2010; Martínez-Solanas et al., 2018) and can become progressively disoriented (CM1), hallucinatory (CM2), and sometimes even aggressive (CM3) (Dorman and Havenith 2009; Conlon et al., 2011)[47,66]. They also suffer from a lack of mental coordination (CM5) and reduced neuro-muscular functions (CM6) (Rodahl 2003; Castellani et al., 2010). Everyone who works in extreme weather is vulnerable to short-term mental health issues like anxiety and depression (Simpson et al., 2011). Table 6 shows the mental challenges and health issues experienced by those who work in cold weather.

Table 2. 6. List of Mental Health Challenges Faced by Workers in Cold Weather Conditions

ID	**Mental Health Challenges**	**Workplace Effects**	**Sources**
CM1	Disorientation	Reduced worker output	Tiwary and Gangopadhyay 2011
CM2	Hallucination	Reduced workplace engagement	Tiwary and Gangopadhyay 2011
CM3	Aggressive	Workplace conflicts, reduced team performance	Simpson et al., 2011; Tiwary and Gangopadhyay 2011
CM4	Psychological stress	Reduced worker productivity	Tiwary and Gangopadhyay 2011
CM5	Lack of mental coordination	Reduced workability in workplace	Tiwary and Gangopadhyay 2011
CM6	Reduced neuro muscular function	Reduced task performance	Rodahl 2003

Note: CM = mental health challenges in cold weather conditions.

Extreme weather events, like very cold weather, not only create an unsafe working environment for the laborers, but also impede the construction process. Extreme winds also cause technical safety challenges in addition to mental challenges. For example, certain construction activities, like the construction of tunnels, are always challenging, but are more so in extremely cold temperatures. Similarly, conditions like extreme wind speed hamper some equipment operations, i.e., cranes, and create risky scenarios for the operator (Shahin et al., 2011). This could impact the mental health of the worker when working in such conditions. Such activities that are weather sensitive should be identified in the planning phase to ensure safe working practices for the workers as well as to reduce schedule delays caused by uncertain weather conditions (Shahin et al., 2011). Small and medium-sized construction enterprises suffer inordinately from extreme weather events, and because of lack of resources, sometimes even need to suspend projects during extreme weather (Wedawatta et al., 2011).

2.8. Management Strategies for Workers in Hot Weather Conditions

Seventeen strategies were identified for hot weather conditions and were presented from least effective to most effective based on the hierarchy of controls provided by National Institute for Occupational Safety and Health (NIOSH) (NIOSH 2015). The hierarchy of controls is comprised of five different types of controls (elimination, substitution, engineering, administrative, and personal protective equipment) that range from most effective to least effective. Elimination is considered the most effective control and personal protective equipment (PPE) is considered the least effective (NIOSH 2015). The strategies identified in this study were categorized based on the hierarchy of controls. As per the hierarchy of controls, any dangerous hazards leading to the death of an individual should be immediately eliminated or substituted (NIOSH 2015; Namian et al., 2021). Planning and scheduling some of the construction activities to cooler hours of the day can help in eliminating heat related hazards. If the hazard cannot be eliminated or replaced, engineering controls can be adopted. Construction sites should be equipped with temporary cool shelters and places to rest with vending machines that offer cold drinks, which will help hydrate the employees. When air conditioning units cannot be installed in a workplace, local and personal microclimate cooling can enable the workers to withstand the high temperatures and can help increase the efficiency of workers (Gao et al., 2018). Psychological strain induced by physiological challenges of working in hot weather can be mitigated by first addressing the physical challenges (Rodahl

2003). Adopting technologies like a Physiological Status Monitor (PSM) and Ultra-Wideband can help monitor heat strain (Yi et al., 2016). The Psychophysiological Monitoring System updates the real time health status of workers to employers when it deteriorates from the norm by a system of sensors (Lundgren et al., 2013).

Liu and Wang (2017), authored papers that espoused that creating an awareness of the problems that can be encountered while working in extreme heat and monitoring the workers' behavior are the traditional methods of addressing heat-related health challenges. Their research incorporated the combined use of a Geographical Information System (GIS) and Building Information Modelling (BIM), along with smart sensors like wristbands attached to the workers, thus creating a smart work site. This provides real time data of the degree of heat stress that the workers are experiencing and acts as an early warning system, alerting employers if their workers are being over-exposed. Table 7 depicts the strategies for protecting workers in hot weather conditions.

Table 2. 7. Strategies for Challenges Caused by Working in Hot Weather

ID	Type of controls	Strategies for hot weather conditions	Related challenges	Sources
1.	Engineering control	Develop a smart work site using GIS and BIM that acts as early warning system to protect workers from heat stress	HP3	Liu and Wang 2017
2.	Engineering control	Employ a Basis Peak Smartwatch to evaluate workers' psychological status based on physical responses	HM7, HM9	Guo et al., 2017
3.	Engineering control	Consider using smart shirts with Bluetooth technology to identify workers at risk	HP10, HM5	Awolusi et al., 2018
4.	Engineering control	Employ an RFID-based ultra-high frequency (UHF) sensor attached to the skin to monitor workers' body temperature	HP1, HP4, HP5	Milici et al., 2014; Podgórski et al., 2017
5.	Engineering control	Use electronic wearables to measure physiological parameters	HP9, HP10	Podgórski et al., 2017

6.	Engineering control	Provide easily accessed vending machines with cold drinks	HP2	Wedawatta et al., 2011
7.	Engineering control	Provide temporary shelters that have cooling capabilities on work sites	HP2	Xiang et al., 2014
8.	Administrative control	Encourage management to implement job rotation	HP2, HP3	Yi and Chan 2015
9.	Administrative control	Encourage workers to consume fluids containing salts and electrolytes	HP4	Morioka et al., 2006
10.	Administrative control	Allow workers to self-pace when exhausted	HP2	Edirisinghe et al., 2019
11.	Administrative control	Encourage workers to consume more liquids	HP11, HP6	Edirisinghe et al., 2019
12.	Administrative control	Assigning more younger workers in activities with increased heat related risks	HP1, HP4, HP5	Yi and Chan 2015
13.	Administrative control	Implement optimized work-rest hours	HP3, HM1, HM2, HM3, HM4, HM5	Yi et al., 2016
14.	Administrative control	Employ pollution control strategies	HP10	Yi and Chan 2013
15.	Administrative control	Restrict alcohol consumption	HP11	Yi and Chan 2013
16.	PPE	Provide personal protective clothing with right fit	HP2	Wagner et al., 2013
17.	PPE	Provide workers with cooling vests	HP9, HM6	Yi et al., 2017

Note: BIM = building information modelling; GIS = geographical information system; HM = mental health challenges in hot weather conditions; HP = physical health challenges in hot weather conditions; PPE = personal protective equipment; RFID = radio frequency identification; UHF = ultra-high frequency.

The impacts of heat stress on workers should be assessed regularly so that an effective management plan can be developed and applied. This requires recording the workers' physiological responses, such as heart rate and blood pressure, which are more accurate in assessing heat stress than the WetBulb Globe Temperature (WBGT) index (Dehghan et al., 2012). Parameters that indicate stress in workers include heart rate, blood pressure, and respiratory rate. These indicators require an electrocardiogram (ECG/EKG) sensor that measures heart activity, and infrared, radar sensors (Awolusi et al., 2018). Other sensors include an electromyography (EMG) sensor, a blood pressure sensor, a breathing sensor that monitors respiration, and motion sensors that record the worker's activity. Several embedded systems are available in the market that can even identify body posture, muscle activity, brain activity, blood pressure, level of hydration, oxygen level, and amount of sleep (Podgórski et al., 2017). Some of the wearable technologies available in the market are The SmartCap Lifeband to measure brainwaves, Muse Headbands to measure to measure brain activity and to obtain real time feedback on performance of the body, Omran's Kardia Mobile 6L to detect cardiac rhythm, Equivital's LifeMonitor to measure heart rate, respiratory rate, body orientation, Kenzen's smart PPE to monitor parameters related to heat stress, Zephyr BioHarness to track ECG data, and Arion Smart Insoles and Footpods to monitor worker's posture.

When attached to the skin, a passive radio frequency identification (RFID) system, based on an ultra-high frequency (UHF) sensor, has the ability to record the body's temperature wirelessly (Milici et al., 2014; Podgórski et al., 2017). Sensors incorporated into fabric, known as e-textiles, can measure the heart's electrical activity, respiration, and other important health indicators, and use flexible substrate to ensure the wearers' comfort (Mukhopadhyay 2015). A smart shirt implanted with Bluetooth technology collects real time data and identifies the workers who are at risk (Awolusi et al., 2018). Respiratory rate is measured through microwave doppler radars. Although several sensors are available that can record parameters individually, incorporating the functions of several sensors into one single sensor is recommended (Awolusi et al., 2018).

Wristbands, which use photoplethysmography (PPG) sensors, can be used to track workers' heart rates and have an advantage over the usual electrocardiogram sensor that has to be positioned near the heart, using a chest strap (Hwang and Lee et al., 2017). In a study conducted by Aryal and his colleagues (Aryal et al., 2017), wearable devices that included a heart rate monitor, infrared temperature sensors, and electroencephalography (EEG) sensors were used to monitor fatigue in construction workers.

Liu and Wang (2017) developed a smart work site to manage workplace heat stress using geographical information system and building information modelling. Three-dimensional Cisco smart sensors were used to monitor environmental conditions of work sites, and they are helpful in displaying and analyzing site data and providing recommendations to alleviate heat stress problems on sites.

Planning is key to reducing health problems when workers are exposed to extreme heat for prolonged periods of time. Administrative controls will be implemented as the next level in the control hierarchy. One of the most effective solution is establishing rest periods, which reduces the number of accidents that might occur, boredom that occurs from performing repetitive activities, renews interest in tasks, and improves productivity (Yi et al., 2016). In general, providing a 15-minute break after 120 minutes of work is effective, but it has been observed that shorter breaks in the morning and longer breaks in the afternoon most effectively reduce mental fatigue and emotional strain. A strict restriction on alcohol consumption also reduces heat stress and dehydration. Pollution control strategies should be adopted in the earliest stage of projects to prevent or mitigate the severity of respiratory issues that workers face due to heavy wind; sand, and other fine particles in dry, hot, and humid environments (Yi and Chan 2013).

Younger workers are less susceptible to heat stress than older workers, but older workers offer years of experience and training. It is, therefore, important that a program be developed where younger workers are assigned in outdoor activities with higher heat related risks (Yi and Chan 2017). Workers who are not used to high temperatures should be acclimatized for a period of one or two weeks (Edirisinghe et al., 2019), and supervisors should be especially vigilant and protective of workers who perform their jobs at great heights and handle power tools (Xiang et al., 2014).

As dehydration is one of most common and dangerous results of working in extremely hot temperatures, workers should be made aware of the ways that it compromises their health and should be encouraged to consume sufficient liquids at regular intervals (Edirisinghe et al., 2019). Heat cramps are common among outdoor workers but can be prevented by drinking adequate fluids that contain salt and electrolytes, as they help keep the body hydrated and facilitate perspiration (Morioka et al., 2006). Workers should be instructed to pace themselves when they are working in extremely hot temperatures (Edirisinghe et al., 2019).

Job rotation is another way to effectively reduce worker fatigue and errors and accidents in the workplace. Those responsible for planning the rotation need to identify the jobs that are eligible for rotation, as well as the most worker-friendly sequence and interval of rotation (Yi and Chan 2015). Employers should be aware and should make their employees aware that not getting enough good quality sleep can cause mental fatigue and reduce perception levels. Sleep monitoring tools are available to track the duration of sleep, and when they reveal a need, sleep aids can facilitate a good night's rest. Workers who are psychologically stressed, whether from lack of sleep or other causes, should know that they can receive help from their supervisors, who will assist them in reaching out to health practitioners for psychological support. Personal protective clothing should fit correctly to ensure comfort, flexibility, and mobility (Wager et al., 2013). A study by Yi et al (2017), was conducted to assess the effectiveness of cooling vests worn by construction workers, and the results revealed that the vests' pre-cooling and post- cooling reduced the amount of cardiovascular strain in workers.

Despite the widespread availability of sensors, wearable devices, and advanced technologies designed to monitor workers' health and ensure workplace safety, the construction industry is reluctant to adopt them. According to Awolusi et al (2020), the construction industry's use of wearable sensors and incorporation of smart technologies are still in the preliminary stage compared to that of other industries, and the technology advantages will only be fully realized when user acceptance is high (Ahn et al., 2019). Therefore, the key to developing a smart construction site is positive user perception and acceptance. The industry has almost attained the highest level of adopting traditional accident prevention strategies; therefore, to further reduce accidents and fatalities, researchers are encouraging professionals in the industry to incorporate smart technologies. Some of the factors that are essential to their adoption are the simplicity of the wearable sensor devices' technology, qualified staff, effective employee training, and adequate budget allocations (Nnaji et al., 2020).

According to a study performed by McGraw Hill Construction, 43% of contractors do not want to incorporate technologies and innovative safety practices. Therefore, it is essential that the advantages of using them be presented in a clear and concise manner that highlights not only how they can be of benefit to the industry, but also to the user (Nnaji et al., 2020). Providing training and education is exceedingly important before they are introduced at the sites so that the workers are comfortable with the technology and understand the basic operations, such as the alerts and notifications, that wearable devices provide. Practices such as providing incentives to workers in the initial phase of implementation can be beneficial for encouraging their use (Jacobs et al., 2019).

2.9. Management Strategies for Workers in Cold Weather Conditions

Strategies for workers in cold weather conditions are presented below in the hierarchy of controls from most effective to least effective (NIOSH 2015). Any hazard that makes the worker prone to death should be eliminated. When workers experience severe cold related injuries, they must be immediately removed from the workplace. Executing some of the construction activities in warmer parts of the day can also help in eliminating cold related hazards. Employers should ensure that workers use a PPE with the right fit. Sufficient and adequately fitted personal protective clothing entraps the body heat of those working in extremely cold weather conditions; however, engineering controls like shelters and adequate heating mechanisms are essential to the workers' comfort, and infrared heaters are effective for preventing numbness in extremities, such as fingers (Antonnen et al., 2009; Conlon et al., 2011). Surfaces of machines exposed to cold weather should also be insulated (Antonnen et al., 2009). Heat exchange masks can help reduce respiratory problems that are due to cold weather (Rodahl 2003). Wearing Peltier embedded cooling jackets can help workers in cold weather, as they have three temperature settings that can protect workers from cold-related deaths (Poikayil et al., 2017). Smart clothing with sensors that monitor the skin temperature, humidity, and body temperature, can also protect outdoor cold workers by providing data on the difference in the temperature inside and outside the jacket, as well as alert signals when workers are working in dangerous conditions. Information collected through smart clothing allows workers to be monitored and protected while working in extreme cold (Seeberg et al., 2011). Workers should wear anti-slip shoes when working on slick surfaces (Antonnen et al., 2009; Bagheri et al., 2019).

Administrative controls that could be implemented include placing appropriate signage for warning of slippery or icy surfaces, can reduce falls and trips, and frequent removal of snow and ice on pathways helps ensure safe walking conditions (Wagner et al., 2013; El-Shafei et al., 2018). Workers who operate manual tools should wear appropriate protective clothing (Antonnen et al., 2009; Bagheri et al., 2019). Workers should be advised not to let their hands contact any extremely cold surfaces (Rodahl 2003). Table 8 lists strategies for mitigating the identified challenges in cold weather.

Table 2. 8. Strategies for Mitigating Challenges of Working in Cold Weather

ID	Type of controls	Strategies for cold weather conditions	Related challenges	Sources
1.	Engineering control	Encourage the use of Smart clothing inserted with InfraRed, humidity and temperature sensors	CP1, CP11	Seeberg et al., 2011
2.	Engineering control	Wear Peltier embedded cooling jacket	CP2, CP6	Poikayil et al., 2017
3.	Engineering control	Heat exchange masks	CP8	Rodahl 2003
4.	Engineering control	Protective coverings and insulation	CP12, CP2	Antonnen et al., 2009
5.	Engineering control	Anti-slippery shoes	CP11	Wagner et al., 2013; Mukopadhyay 2015
6.	Engineering control	Provide workers with infrared heaters	CP2	Antonnen et al., 2009
7.	Engineering control	Provide warming facilities/local shelters that have heating mechanisms	CP17	Antonnen et al., 2009
8.	Administrative control	Cold protection plan and cold management	CP1	Rodahl 2003
9.	Administrative control	Place warning signs on slippery surfaces	CP11	Antonnen et al., 2009
10.	PPE	Ensure PPC fits properly	CP3, CP15	Antonnen et al., 2009; Conlon et al., 2011

Note: CP = physical health challenges in cold weather conditions; PPC = personal protective clothing; PPE = personal protective equipment.

Cold protection plans and safety training for workers are essential for worker safety and should be developed and mandated at the organizational level. An effective plan of work-rest breaks and other preventative measures can be implemented at job sites for the workers' safety (Rodahl 2003).

2.10. Conclusion

Safety is always the number one priority for construction workers, and those who work in environments that are either extremely hot or extremely cold require additional protection. This paper identifies the challenges and health issues that workers in extreme weather conditions encounter. Numerous physical conditions like cardiac strain, heat rash, respiratory problems, heat strokes, heat-related cramps, heat-related edema, chronic kidney disease, and hypertension were identified as impacts of working in extreme hot weather. These physical impacts often cause workers to become less productive, bored, irritable, angry, anxious, moody, etc. and the physical and mental challenges also make them more prone to accidents and injuries, such as amputations, burns, falls, and trips. Other effects of working in extreme cold weather are trench foot, hypothermia, frostbite, necrosis, vasoconstriction of blood vessels, respiratory issues, hypothermia, and reduced dexterity. Mortality and morbidity due to cardiovascular diseases are more common in cold weather conditions because of vasoconstriction of blood vessels. Workers in cold weather gradually become disoriented, hallucinatory, and aggressive. They also face mental challenges like increase in temper, irritation, and psychological stress due to working in cold weather conditions. Some of the strategies identified in this study for workers in hot weather conditions are implementing optimized work-rest hours, restricting the alcohol consumption in workers, encouraging workers to self-pace, motivating workers to consume more fluids containing salts and electrolytes, and preparing the work sites with temporary cooling facilities. Employers in cold weather conditions should make sure that workers receive PPC with the right fit, worksites should have sufficient warming facilities/shelters with heating mechanisms, encouraging the use of heat exchange masks for respiratory issues and local infrared heaters to reduce manual dexterity are some of the strategies that can be implemented to reduce the effects of cold on worker’s health. Workers can be educated about the impact of hot and cold weather on their health by providing them safety training.

A small number of construction workers are particularly vulnerable to health issues caused by working in extreme hot weather. The literature revealed that older workers are more impacted by heat stress than younger workers, female workers are more affected than male workers, and obese and underweight workers are at higher risk of heat stress. Expatriate workers also suffer more from effects of extreme weather conditions, as they are not used to local weather conditions. In cold weather conditions, elder individuals and females are more likely to experience cold weather health issues than their counterparts. However, only very few studies focused on the vulnerabilities based on demographic characteristics of individual in cold weather conditions as compared to hot weather conditions.

This study bridges the knowledge gap by identifying the health challenges that construction workers may experience due to working in extreme weather conditions and by developing appropriate strategies for mitigating or eliminating them. Classifying the strategies according to the hierarchy of controls will help those who are responsible for minimizing hazards on construction sites take more effective actions. Identifying the most vulnerable workers can be beneficial to construction as they plan, allocate tasks, and prioritize safety. Hence, this study marks the importance of extreme weather conditions on construction workers' health and safety. Despite the study's advantages, however, a few limitations need to be mentioned. The primary limitation is that it only identifies a few of the mental health challenges experienced by those who work in extreme cold, which is due to a dearth of information in the literature. Also, the strategies identified in this study primarily pertain to administrative and engineering controls and others should be investigated more thoroughly in future research. The intent of this paper is to contribute to the understanding of construction industry professionals as they seek to mitigate or eliminate health challenges faced by workers in extreme weather conditions. It is also hoped that it will enable future researchers to develop solutions and strategies for the challenges faced every day by those who work in extreme environments.

CHAPTER 3

EVALUATION OF HEALTH CARE COSTS FOR WORKERS IN EXTREME WEATHER CONDITIONS

3.1. Abstract

The number of deaths and minor and severe injuries in the construction industry are increasing every year and are directly related, at least in part, to the rising number of extremely hot and cold days caused by climate change. The lack of sufficient federal laws on safety enforcement for workers performing in extreme weather conditions has also contributed to the dilemma. This paper evaluates the health care costs that are associated with construction workers performing in hot and cold weather conditions by performing a descriptive analysis. A questionnaire survey was developed and distributed to a variety of workers involved in the construction sector, and 100 responses were received. An analysis of the results revealed that construction workers exposed to extreme hot and cold weather incur more health care expenses than workers in a thermo-neutral environment, male construction workers spend more on medical care than females, health care costs increase as workers age, and those who have higher medical bills suffer from more health issues. The results of this study will help construction professionals understand the health care cost claims of workers performing in extreme weather conditions.

Keywords: Health Care, Costs, Hot Weather, Cold Weather, Field Workers

3.2. Introduction

A disproportionate quantity of work-related accidents and injuries occur in the construction industry every year, making it one of the most hazardous industries in which to work. Despite employing only 8% of the total U.S. workforce, 22% of the work-related deaths in 2005 occurred in the construction industry (Dong et al., 2007). Construction workers have consistently had the highest rates of injuries, illnesses, and fatalities of any sector (Friedman et al., 2009; Karthick et al., 2022h), and the average rate of non-fatal injuries and illnesses that lead to absences from work is higher than that of other employment sectors (Dong et al., 2007). Occupational accidents and diseases aren't only about safety and wellbeing, however; they're also about economics. Workplace injuries consume resources, which means that they can't be used for other purposes (Dong et al., 207; Pamidimukkala and Kermanshachi 2022). The increasing number of days with extreme weather conditions have resulted in increased health challenges, and the Intergovernmental Panel on Climate Change projects that "*It is very likely that hot extremes, heat waves and heavy precipitation events will continue to become more frequent*." Epidemiological models indicate that an increase of one day of hot weather increases the number of fatalities by roughly 7% and hospital admissions by 1.2–1.4%. Likewise, an increase of one cold day indicates a 8-9% mortality (Karlsson and Ziebarth 2018). A body naturally thermoregulates, (Cheung et al., 2016; Karthick at al. 2022f), but when it is continuously exposed to harsh weather, it is unable to regulate its internal temperature, which results in a wide array of physical and mental health problems (Cheung et al., 2016; Renberg et al., 2020; Rouhanizadeh & Kermanshachi 2021). Acute and chronic illnesses, diseases, malignancies, and disorders may be caused by temperature-related hazards (Yi and Chan 2016), and deaths from heat stroke, impaired physiological processes, and organ damage are only a few of the consequences of heat stress (Mohraz et al., 2016; Karthick et al., 2022d). Workers experience numbness, frostbite, respiratory issues, frequent slips and fall-related accidents during cold weather conditions (Ikäheimo and Hassi 2011).

The cost attributed to the vast number of construction injuries and illnesses is enormous (Friedman et al., 2009). In the United States, the annual cost for construction workers' accidents and illnesses is as high as $12.7 billion dollars (Waehrer et al., 2007; Friedman et al., 2009). Several findings have focused on the annual costs related to construction workers' mortality, but the extent to which extreme weather affects their annual health care costs is unexplored. Therefore, this study aims to descriptively analyze the health care costs incurred among various subgroups based on age, gender, ethnicity, work environment, and type of construction sector in which they are employed. The results of this study can assist employers in understanding the health issues encountered by workers in extreme weather and the associated health care compensation claims and costs.

3.3. Literature Review

3.3.1. Health Care Costs and Extreme Weather Conditions in Construction Sites

Heat exposure at the workplace can cause serious health challenges, such as an increase in the probability cardiovascular problems, and impedes workers' capacity to live healthy and productive lives (Ioannou et al., 2021). Long periods of hard labor in hot weather conditions are common in industries such as tourism, construction, and agriculture, where being exposed to the elements is the norm and no cost-effective heat reduction techniques are being implemented. By the year 2030, labor loss due to heat is expected to reach 2400 billion USD (Ioannou et al., 2021). In high-income countries, heat, particularly abrupt heat waves, is one of the most common causes of death and increased emergency room visits and hospital admissions. Cardiorespiratory illnesses (Rodahl 2003), kidney disease, hypothermia and other diseases, mental health issues, adverse pregnancy and birth outcomes (Rahman et al., 2016), and increased health-care costs (Ebi et al., 2021) are all potential consequences of working in extreme heat (Ebi et al., 2021; Adepu et al., 2022). A healthy human physiology adjusts to moderately high and low temperatures by monitoring the changes in skin and core body temperatures. Bodies react to heat by vasodilation (enlarging of blood vessels), an increased rate of cardiac output, and perspiration, which result in a considerable drop in blood pressure and can lead to other complications such as loss of consciousness, vomiting, headache, muscle weakness, dizziness and nausea. Heat stroke can also result in death or permanent brain damage (Gronlund et al., 2018; Karthick et al., 2021). Workers who have high cholesterol are at greater risk of a heart attack, and many outdoor workers experience severe musculoskeletal disorders, which can manifest themselves in a variety of places, including the upper back, shoulder, lower back, neck, ankle, forearm, knee, upper arm, hip, and elbow (Pamidimukkala et al., 2021), with those involving legs, including knees; the lower back, neck, and shoulder being the most common. Repetitive manual tasks and longer shifts are two of the primary reasons for work-related MSD symptoms (Goldsheyder et al., 2004; Yi and Chan 2016).

In cold temperatures, arteries constrict, resulting in reduced blood flow. Hypothermia, which causes confusion and drowsiness, develops when the core temperature is lowered (Gronlund et al., 2018). Respiratory disorders in the lower and upper tracts may occur when a worker is frequently exposed to extremely cold conditions (Rodahl 2003; Sugg et al., 2019), and pre-existing health concerns such as cardiovascular disease, asthma, and bronchitis may be exacerbated (Suggest al., 2019). Cold weather and low moisture levels in the air cause skin problems such as dryness and itching and increase the incidence of accidents that involve slips and falls due to icy and slippery surfaces (Rodahl 2003; Pamidimukkala and Kermanshachi 2022). Workers may also experience lack of coordination and manual dexterity while handling tools (Tiwary and Gangopadhyay 2011), which can contribute to accidents and reduced productivity. Lipscomb et al. showed that the healthcare expenses for accidents involving falls were three times more for workers aged 45 years and older than for those 30 years and younger (Lipscomb et al., 2003; Schwatka et al., 2012). Older constructions workers are at a higher risk of long-term disabilities than younger workers (Schwatka et al., 2012), and those with jobs as scaffolders, roofers, and steel fixers, who work at elevated heights, are more susceptible to occupational illnesses caused by extreme weather conditions

(Fredericks Tycho et al., 2005; Wong et al., 2014). In summary, despite several studies focusing on the health issues faced by workers as a result of extreme temperatures, an in-depth investigation into health care expenses incurred by workers performing in extreme weather conditions is needed.

3.4. Research Methodology

A study of the existing literature on occupational illnesses and injuries due to extreme weather conditions was performed by employing search engines such as Google Scholar, PubMed, ASCE, ResearchGate, Springer, and Elsevier. Then, based on the extensive literature review, a questionnaire survey was developed through the online platform QuestionPro. The participants for the survey were selected by perusing websites of private companies and professional platforms such as LinkedIn. The survey participants were not compensated for their participation. The participants were required to be over the age of 18 and working in a construction-related sector of the construction industry. The survey consisted of 60 questions, most of which were 7-point Likert scale questions, with the addition of a few demographic questions to better understand the characteristics of the respondents. In the third step, the survey was distributed through an online platform and 100 responses were collected. In the fourth step, the collected data were classified based on health care costs spent by the respondents, and in the fifth step, the classified groups were descriptively analyzed and various aspects such as age, gender, job position, ethnicity, work environment, and type of construction sector in which they were employed were compared.

3.5. Results and Discussion

The data from the survey were classified into three categories: Group 1 (workers who spent more than $500 annually for health care), Group 2 (workers who spent between $250 and $500), and Group 3 (workers who spent less than $250). The health care costs were visualized based on job positions, which were classified into three major job positions: Owners and vice presidents of companies, project managers and office workers, and fieldworkers. Figure 3.1. below illustrates the health care costs of each group, where it can be observed that more field workers spent in excess of $500 annually for healthcare than those in managerial positions. This could be attributed to their work environments, as the field workers are more frequently exposed to unfavorable weather conditions than office workers who are in a temperature-controlled work environment. The graph below indicates the annual health care costs spent by the workers based on their job position.

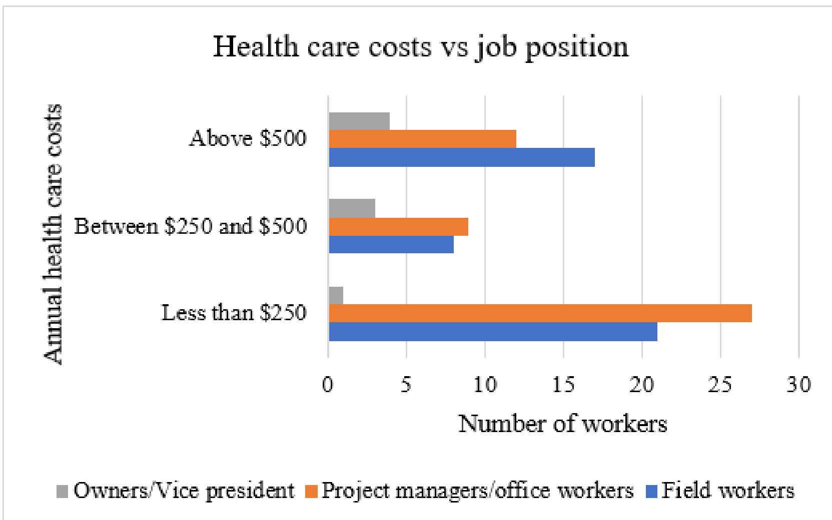


Figure 3. 1. Health Care Costs (HCC) Based on Job Positions

Based on the above trend, the workers who spent more than $500 and workers who spent less than $250 are compared to understand the aspects behind the variations in annual healthcare costs. Figure 3.2. presents the responses of workers who spent above $500 and the illnesses that they sought medical care for.

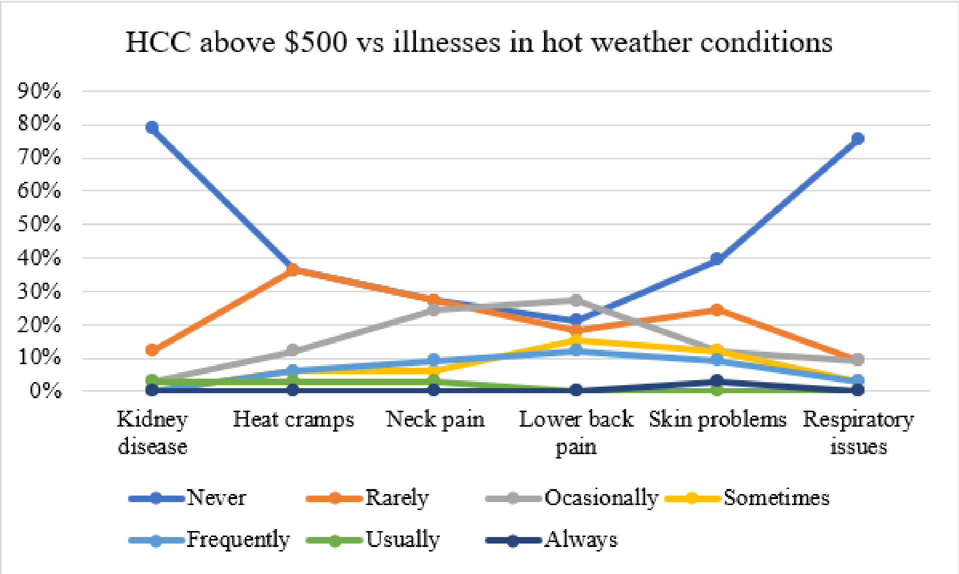


Figure 3. 2. Health Care Costs (HCC) and Illnesses of Workers Who Spent Above $500 Annually

Workers who spent more than $500 experienced more back pain than workers who spent less than $250. The survey indicates that 27% of the workers who spent above $500 experienced lower back pain, but none of the workers who spent less than $250 experienced it. Figure 3.3. indicates the responses of workers who spent less than $250.

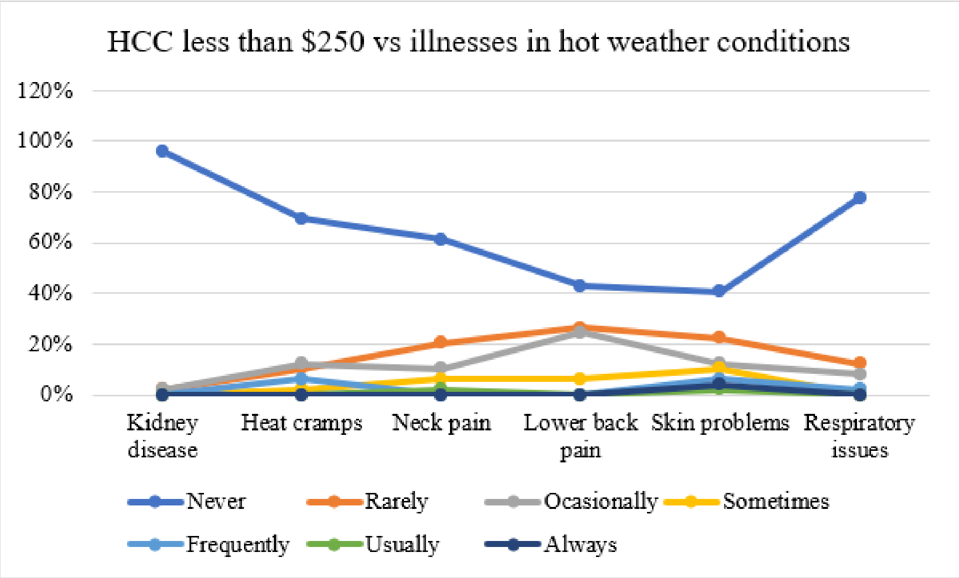


Figure 3. 3. Health Care Costs (HCC) and Illnesses of Workers Who Spent Less $250 Annually

Figure 3.4. presents a comparison of the number of males and females who spent more than $500 and less than $250 for health care annually, and it can be observed that 97% of those who spent more than $500 and 84% of those who spent less than $250 were males. This may well be attributed to the much larger percentage of males who are employed as field workers and are exposed to extreme weather conditions.

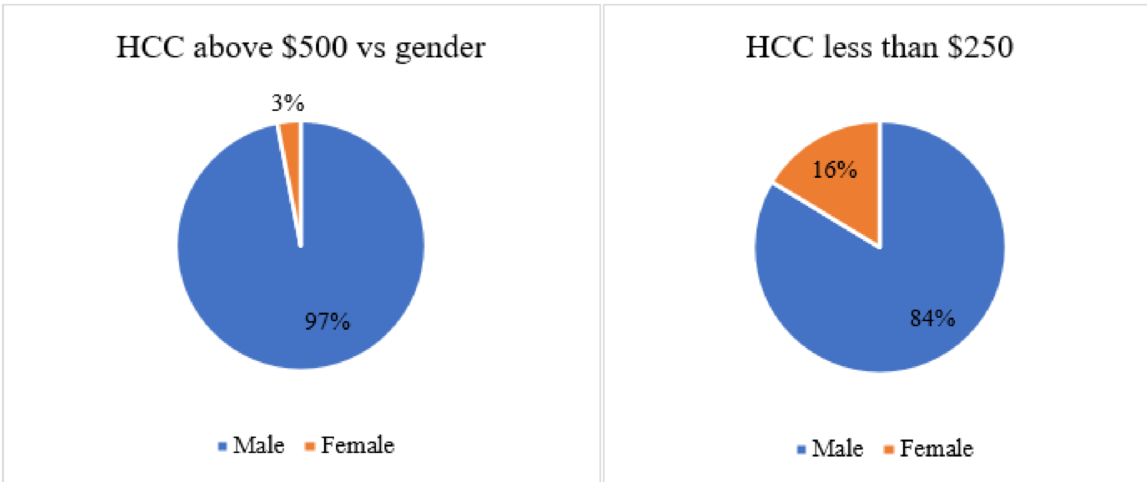


Figure 3. 4. Comparison of HCC Above $500 and Less Than $250 Based on Gender

Workers above 51 years of age spent more on health annually in both groups (those who spent less than $250 and those who spent more than $500). Figure 3.5. depicts the numbers of workers who spent more than $500 and less than $250 based on age.

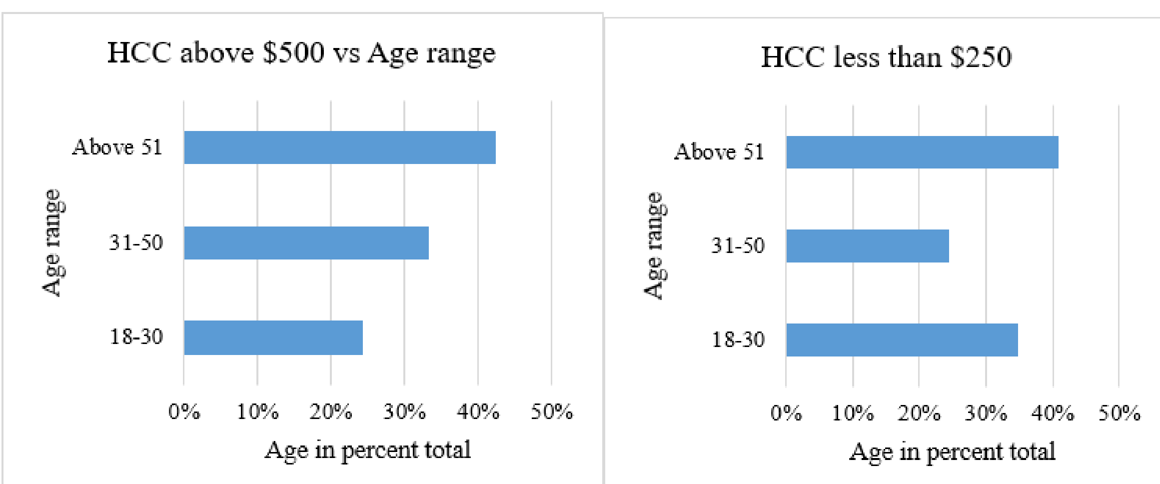


Figure 3. 5. Comparison of HCC Above $500 and Less Than $250 Based on Age

Based on the above figure, it can be inferred that workers above 51 years of age experience more health issues than those in other age groups. The health care costs were also classified based on the construction sector and are shown in Figure 3.6. The graph below indicates that 78% of the workers from the heavy industrial sector spent more than $500 for annual health care costs, while none of the other workers did. This indicates that workers in the heavy industrial sector might face more health issues compared to workers in other sectors.

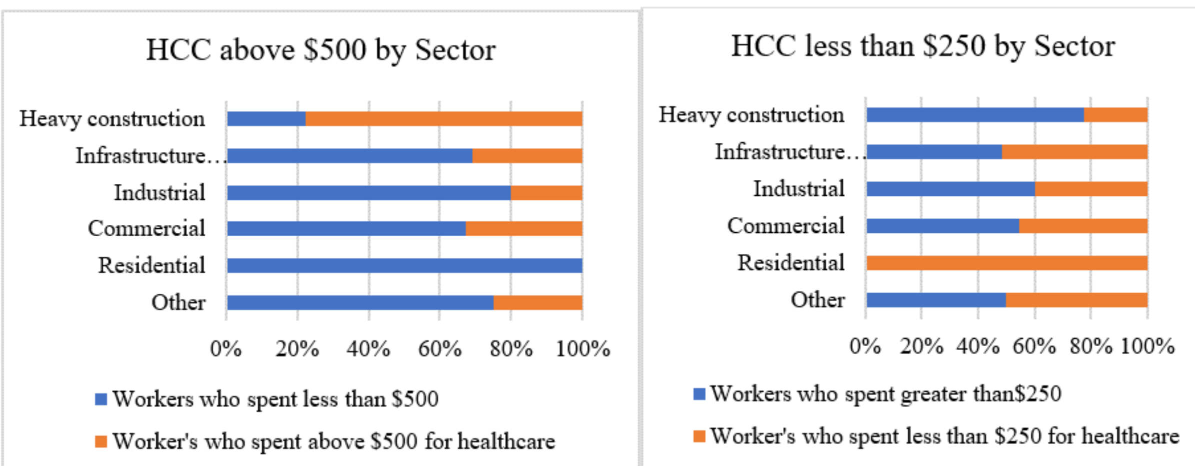


Figure 3. 6. Comparison of HCC Above $500 and Less Than $250 Based on Construction Sector

A higher percentage of Caucasians and African Americans spent more on healthcare, followed by Asians and Hispanics. Figure 3.7. compares the health care costs of people of various ethnicities.

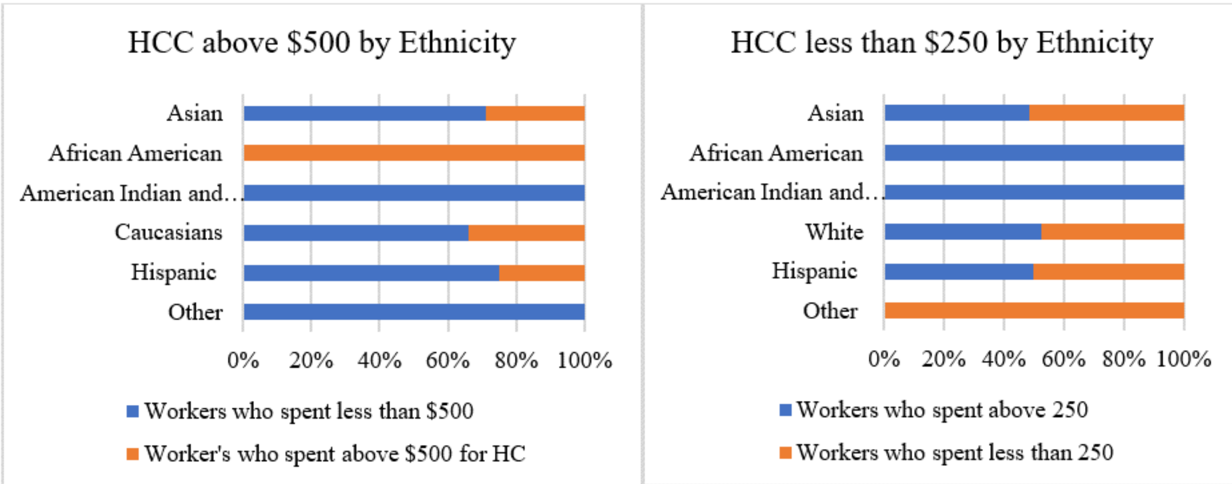


Figure 3. 7. Comparison of HCC Above $500 and Less Than $250 Based on Ethnicity

Work environments can make a difference in the health care costs of workers. According to the survey, those who work outdoors spend more on health care annually than those who work indoors. Figure 3.8. shows the relationship between the type of work environment and the amount of money spent annually on healthcare.

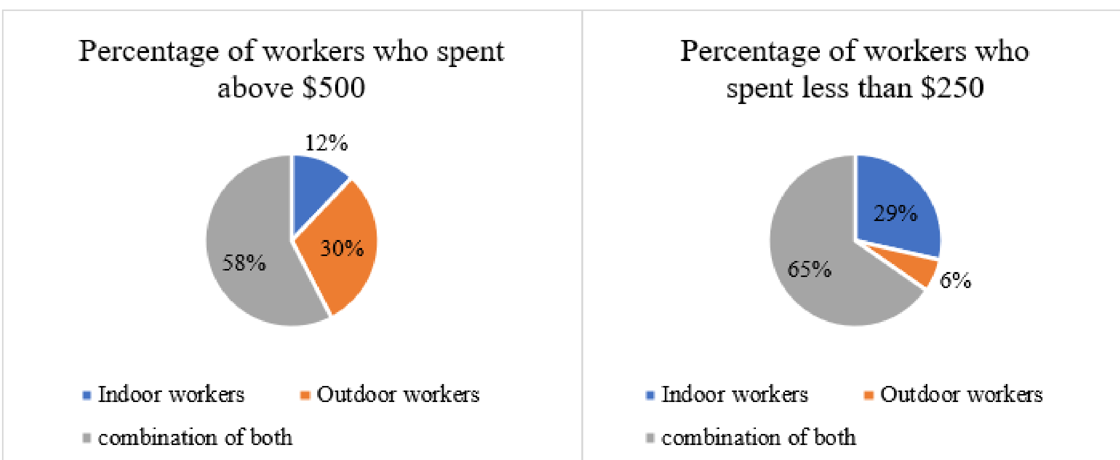


Figure 3. 8. Comparison of HCC Above $500 and Less Than $250 Based on Work Environment

The higher percentage of indoor workers who spent less than $250 annually for healthcare indicates that workers exposed to unfavorable weather conditions incur more medical expenses, as they are more prone to health issues related to extreme weather conditions.

3.6. Conclusion

A questionnaire survey was developed and used to provide the basis for a descriptive analysis of the health care costs of construction workers who labor outside in extreme weather conditions. The study revealed that field workers incur more healthcare costs than those in managerial positions since they are more exposed to unfavorable working conditions, and workers above age 50 have higher medical costs than workers in other age groups. This finding correlates with previous and existing literature studies that show that older workers are more prone to health disorders when exposed to extreme weather conditions and require special attention, care, and strategies to ensure their safety and health. The analysis also revealed that workers in the heavy construction sector spend a higher percentage of healthcare costs than workers in other construction sectors (residential, commercial, infrastructure sectors) and that workers who work in outdoor environments incur higher costs than workers performing in indoor environments. The results of this study can be used to develop a cost model for at-risk workers that will help professionals in construction companies better understand the health issues encountered by workers in extreme weather and the associated health care compensation claims and costs.

CHAPTER 4

ANALYSIS OF THE HEALTH AND SAFETY CHALLENGES FACED BY CONSTRUCTION WORKERS IN EXTREME HOT WEATHER CONDITIONS

4.1. Abstract

Climate change has led to a rising number of extremely hot days globally, making those who work outside more vulnerable to heat-related illnesses such as heat syncope, exhaustion, heat edema, and heat stress. The objective of this article is to identify and analyze the challenges experienced by construction workers who work in extremely hot weather conditions for extended periods of time. To achieve this objective, a questionnaire was developed and distributed through the online platform, QuestionPro. The 100 responses that were collected were analyzed using the Kruskal-Wallis test and analyses were performed based on physiological indicators such as heart rate and blood pressure, and personal indicators such as climate acclimatization and clothing comfort. The results of the analyses revealed that challenges such as physical fatigue, dehydration, excessive sweating, inability to concentrate, and frequent mood fluctuations were unique to individuals, based on their acclimatization level, heart rate, and blood pressure. Optimized work-rest hours, the provision of adequate time for workers to acclimate to the extreme conditions, adoption of technologies such as cooling vests and continuous monitoring of workers' physical parameters are some of the strategies that can be adopted to protect workers from heat-related health hazards. The article also briefly discusses the practices and regulations that are currently in effect to protect construction workers who are exposed to prolonged hot weather conditions. The findings presented in this article will help professionals in the construction sector effectively manage and safeguard workers' safety in extreme hot weather conditions.

Keywords: Worker Safety, Worker Health, Extreme Hot Weather, Health Challenges

4.2. Introduction

The greater number of extremely hot days that are occurring globally have increased morbidity and mortality rates, especially for those who work outdoors. Extreme heat is a major cause of death in high-income countries and is linked directly with an increase in the number of emergency room visits and hospital admissions (Ebi et al., 2021). The Bureau of Labor Statistics (BLS) reports that an average of 3,507 heat-related ailments and injuries occurred annually from 2011 - 2019 (Bureau of Labor Statistics, September 10, 2021b). The majority of the global population is exposed to extreme hot weather conditions and more than one-third of them suffer adverse health effects as a result. These health problems can be reduced, however, by exploring the challenges of prolonged exposure to heat and implementing efficient heat protection strategies to protect outdoor workers and reduce the number of accidents in the workplace (Kiefer et al., 2016).

Heat stress is one of the potential health challenges of people who are frequently exposed to high temperatures for prolonged periods of time and is more burdensome for those, such as construction workers, who perform physically demanding jobs. Heat cramps, heat stroke, heat syncope, heat edema, heat fatigue and heat exhaustion are all-too-common symptoms (Kiefer et al., 2016; Acharya et al., 2018; Karthick et al., 2022d) that they experience. Chronic kidney disease is one of the most serious problems that can be related to the heat, and co-morbid factors such as cardiovascular disease, as well as medications for pre-existing diseases, can also impact workers' physiological responses. Pregnant women's fetuses are at an increased risk for teratogenic effects (Acharya et al., 2018), and older workers, females, those with a high body mass index (BMI), and Hispanics are most vulnerable to heat-related issues (Acharya et al., 2018). Cognitive impairment, mental fatigue, and lower levels of concentration can also be effects of heat exposure and play significant roles in increasing the number of accidents and compromising workplace safety (Kiefer et al., 2016; Karthick et al., 2022f).

Physiological factors, coupled with environmental indices, can be used to assess the influence of extreme weather on human health. Physical indicators such as an increase in heart rate, blood pressure levels, oxygen intake, and personal indicators such as clothing, age, drinking habits, and acclimatization affect physiological responses to extreme weather conditions (Pilch et al., 2014; Yi and Chan 2015). The environmental indicators include humidity, temperature, wind speed, pollution and radiation (Yi and Chan 2015).

The construction industry experienced a higher number of heat-related injury (HRI) claims than usual from 2006 to 2017, accounting for 26% of all heat-related claims, according to Washington's workers' compensation data (Hesketh et al., 2020). Despite the increasing number of heat injuries, however, few regulatory standards are in place to protect workers (Kiefer et al., 2016) and the ones that do exist are too general in nature to be of much use (Gubernot et al., 2014; Arbury et al., 2016). Therefore, the objective of this paper is to (1) outline the physical and mental challenges that affect workers in the construction industry who work in extremely hot weather conditions, (2) analyze the health challenges that they face, based on physiological indicators such as heart rate and blood pressure, and (3) analyze the challenges based on personal indicators such as whether they have been acclimatized to the weather and the comfort of their clothing. To achieve these objectives, a self-administered survey was developed and distributed to the affected population to understand and analyze the challenges faced by workers on construction sites in very hot weather. The results of this study will help lawmakers and professionals in the construction industry develop guidelines and standards for protecting workers from climate-related health hazards.

4.3. Literature Review

4.3.1. Thermoregulation in Extreme Hot Temperatures

Human bodies sweat to maintain a stable core body temperature (CBT) in response to an imbalance caused by environmental or metabolic heat exposure, and heat stress results when the body is not capable of regulating its core body temperature (Cramer and Jay 2016). A change in body temperature may arise from environmental factors, cutaneous vasodilation, or body morphology such as body mass and composition (Havenith 2001; Cramer and Jay 2016; Acharya et al., 2018); the combination of perspiration and environmental factors contribute to heat loss. The environmental factors include the air temperature, humidity, velocity, and density. Clothing properties affect cutaneous vasodilation, which includes the surface area of the skin, skin dampness and skin temperature. When the body is unable to dissipate heat or is subjected to an internal rise in metabolic heat, the core body temperature fluctuates (Cramer and Jay 2016; Beker et al., 2018).

4.3.2. Health Challenges in Hot Weather Conditions

Workers with heat stress may experience cramps, edema, syncope, a rash, and heat exhaustion (Acharya et al., 2018; Karthick et al., 2022h). Heat cramps are caused by a loss of fluids and/or salts, or a reduced fluid intake (Grubenhoff et al., 2007; Ćurić et al., 2022) and manifest in the form of muscle spasms in the feet, hands, or the abdomen, especially during physical exertion in high temperatures (Schulte and Chun 2009). They are not dangerous but can cause severe pain and discomfort. Some of the other symptoms of heat cramps include physical fatigue, excessive perspiration, dizziness, and total body weakness (Lee et al., 2018; Ćurić et al., 2022). Heat rash occurs due to excessive sweating, when sweat ducts are blocked and prevent the sweat from reaching the skin's surface. It may appear in the form of small red blisters, and symptoms include pain, swelling, and red patches (Moda et al., 2019; Ćurić et al., 2022). Heat exhaustion is a serious condition that occurs when the body loses electrolytes. Symptoms of heat exhaustion include headache, nausea, dizziness, and rapid breathing (Pradhan et al., 2013; Ćurić et al., 2022). Heat edema is indicated by symptoms like occasional swelling of the face and extremities. Heat syncope is an exercise-related collapse, as it often occurs after heavy exertion in elevated temperatures (Lucas et al., 2014; Gauer and Meyers 2019). Symptoms of heat syncope include light headedness and loss of consciousness (Gauer and Meyers 2019). Heat stroke is a dangerous result of performing strenuous activities in elevated temperatures, as it can lead to a coma, organ damage, and even death when it is not treated (Jia et al., 2016; Gauer and Meyers 2019; Ćurić et al., 2022). Dehydrated workers in hot and humid or hot and dry environments are also at risk of developing chronic kidney disease (Bouchama and Knochel 2002; Eaton et al., 2002; Bates and Schneider 2008; Acharya et al., 2018; Tseng et al., 2020; Liu et al., 2021), cardiovascular diseases, hypertension, and respiratory issues (Rodahl 2003; Cheung et al., 2016; Wu et al., 2019).

As opposed to the physiological reactions of hypothermia that occur in cold weather with the body's effort to sustain heat, hyperthermia occurs in hot weather conditions when the body's regulatory system needs to dispel excess heat. This is considered an important mechanism, as it helps prevent heat strokes (Bouchama and Knochel 2002; Beker et al., 2018). Workers may also experience respiratory issues like difficulty breathing and gastric problems and diarrhea may occur when the hepatic organ is injured during a heat stroke (Cheshire 2016; Beker et al., 2018).

Reduced mental performance, mental fatigue, anxiety and loss of concentration are also observed in workers exposed to elevated temperatures (Morioka et al., 2006; Bates and Schneider 2008; Piil et al., 2017; Shibasaki et al., 2017; Ebi et al., 2021), as are increased irritation, anger, confusion, emotional stress, and depression (Schulte and Chun 2009; Al-Maskari et al., 2011).

Heat stress affects not only humans but also construction projects, as it can increase the number of accidents and delay the completion of projects due to the lower productivity of the workers that stems from their impaired physical and mental capabilities (Zander et al., 2015). An increase in the number of fatal accidents may be attributed to reduced visual perception, delayed responses, and reduced mental alertness and associative learning (Rowlinson et al., 2018; Varghese et al., 2018). Figure 4.1. summarizes workers' physical and mental challenges in hot weather conditions.

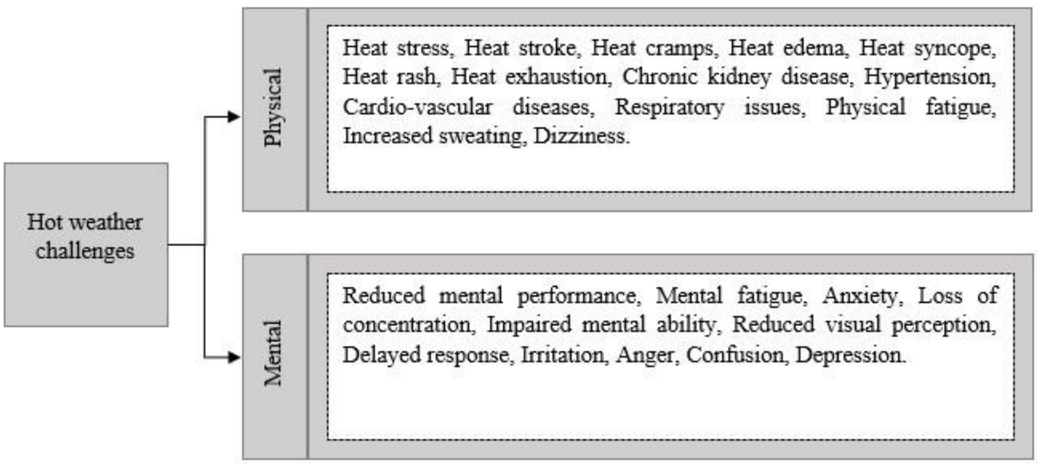


Figure 4. 1. Physical and Mental Challenges in Hot Weather

4.3.3. Population Vulnerable to Extreme Hot Temperatures

The health effects of extremely hot temperatures vary with individuals, based on risk factors such as age, gender, ethnicity, occupation, and skill levels. Older workers, especially those above 55 years of age, are more vulnerable to extreme hot temperatures (Xiang et al., 2014; Rameezdan and Elmualim 2017), and females are more susceptible to heat stress than males. Heat stress also has profound effects on pregnancy and is known to have teratogenic effects on the fetus (Flocks et al., 2013; Xiang et al., 2014; Rahman et al., 2016). Hispanic workers are more vulnerable to high temperature extremes than non-Hispanics (Culp et al., 2011; Acharya et al., 2018), as are those responsible for tasks such as scaffolding, roofing, bar bending, and steel fixing that expose them to direct sunlight at elevated heights for long periods of time, (Chang et al., 2009; Bourbonnais et al., 2013; Wong et al., 2014). Workers who are new to local weather conditions are more vulnerable than those who are acclimatized to the weather (Bates et al., 2010), and workers with a higher body mass and those who are underweight are more prone to the consequences of heat (Acharya et al., 2018; Umar and Egbu 2020).

4.3.4. Existing Standards and Regulations for Workers in Extreme Hot Weather

The Occupational Safety and Health Administration (OSHA), encourages those who work in elevated temperatures to take rest periods and stay hydrated (OSHA 1970), and places the responsibility for workers' safety on employers, but does not provide specific guidelines for protecting them from heat-related health and safety hazards (Arbury et al., 2016). A literature study performed by Arbury et al. (2016) revealed that construction site supervisors pay little attention to acclimatization practices, nor do they monitor their workers and make adjustments to the workplace according to weather conditions (Arbury et al., 2016).

In the United States, only a few states, including California and Washington, have developed detailed heat regulation standards. The Bureau of Labor Statistics (BLS) produces annual reports on workplace injuries and fatalities, but the reports are not optimal. It is therefore imperative that public health surveillance data be made available to employers to help them understand the magnitude of potential occupational illness resulting from heat, to enable them to identify the workers at risk, and to develop preventive measures (Gubernot et al., 2014).

Heat stress is an occupational hazard that is a rising concern globally and knowledge about the heat-related guidelines and regulations that are enforced in other countries could help other countries develop their own. Countries like the United Arab Emirates (UAE) and other gulf countries have extreme heat and arid or desert-like conditions where the temperature may soar above 50 degrees Celsius, but despite their hazardous working conditions, the UAE construction industry is one of the most successful due to their stringent labor laws and efficient utilization of labor in hot weather conditions. Workers there are not permitted to work from 12:30 p.m. to 3:30 p.m. in the hottest months of June and July (Shah et al., 2019), and a “safety in the heat” program attempts to reduce heat-related illnesses based on a thermal work limit (TWL) and heat stress index (HSI) (Joubert et al., 2011; Leonidas et al., 2022). In Bahrain, all outdoor construction work is banned from noon to 4:00 pm during the summer months according to the guidelines by international labor organization (ILO) (ILO 2014).

Australia has also recorded several heat-related deaths due to rising temperatures and increased humidity, but they do not have regulations that are designed to protect outdoor laborers. Various states within the country have, however, adopted interventional guidelines such as encouraging hydration, allowing the employers to self-pace, and establishing thermal work limits (Al-Bouwarthan et al., 2019; Shah et al., 2019). The Construction, Forestry, Mining and Energy Union introduced specific heat stress guidelines stating that outdoor workers need to cease work activities when the temperature is above 37 degrees Celsius; however, it is not widely complied with, as it is not mandated throughout the whole country (Xiang et al., 2015; Shah et al., 2019).

The summer months in Hong Kong are brutal for outdoor workers because of the extremely hot and humid weather (Yi and Chan 2017; Shah et al., 2019). Their legislation is similar to Australia’s, in that they do not have specific policies for employers to follow to ensure safe working conditions for their employees, but they do strongly recommend giving the workers an additional 15-minute break during the summer months. This improves the productivity of the workers and aids in the recovery of their physiological systems (Shah et al., 2019). According to the Chinese Ministry of Health, employees receive a high temperature allowance and work limited hours when the temperature is above 40 degrees Celsius (Leonidas et al., 2022).

It is often challenging to diagnose occupational injuries because of similarities in clinical presentation, delayed onset of symptoms, and lack of communication between workers and employers, and heat-related illnesses are under-reported and under-diagnosed because many employees fear termination of employment and fewer economic incentives (Gubernot et al., 2014). These are but some of the issues that highlight the need for heat regulation policies for the outdoor worker population (Gubernot et al., 2014). Others are the increase in the number of accidents that result in legal issues and increased insurance premiums (Torres et al., 2013), and the loss of productive hours that may affect the project's schedule and cost. Inadequate communication pertaining to the issues that the workers encounter and a lack of identification and understanding of their challenges affect the workers' performance (Oko 2022; Safapour et al., 2022b).

4.3.5. Physiological and Personal Indicators for Hot Weather Conditions

Heat strain is the physiological and psychological response of the body to heat stress. Various methods can be used to evaluate heat strain in individuals (Yi and Chan 2015), one of which is environmental monitoring based on the WBGT (WetBulb Globe Temperature) index and heat index, which is recommended by the National Institute for Occupational Safety and Health (NIOSH). WBGT is also used for workers who are acclimated to the heat but are hydrated and need salt in their systems; however, the lack of access to water and salt on some construction sites limits its adoption (Golbabaei et al., 2021). In such circumstances, Golbabaei et al. suggest using the WBGT index along with other indices and physiological parameters to evaluate heat stress in individuals. The use of WBGT requires trained personnel and financial resources for procuring the instruments (Dillane and Balanay 2020).

Another method for discerning the effects of body heat is through physiological monitoring. Physiological parameters, such as heart rate and core body temperature, have been used to predict heat stress in hot environments (Yao et al., 2018, Yi and Chan 2015). Workers involved in occupations like construction, firefighting, and the military are often exposed to extreme weather while wearing uncomfortable protective clothing that is layered, bulky, made of unbreathable fabric, and uniformly rather than individually designed, which makes it either too tight or too loose. This impedes the evaporative heat loss process and further increases the body's temperature and heat strain. Acclimatization of workers prior to their beginning work is considered important for those who work in extreme hot weather conditions (Rowlinson et al., 2014), as an acclimatized worker can withstand heat for a longer duration with fewer negative effects on their health. Therefore, the acclimatization of workers and their clothing ensemble are two of the personal factors that should be considered when attempting to reduce heat-related occupational hazards (Cheung et al., 2000; Nazarian et al., 2021).

Heat strain is also affected by behavioral factors, such as hydration, age, gender, clothing, physical fitness, alcohol use, and medical conditions. Workers can also evaluate their own levels of heat strain by self-assessing their levels of exertion. This is known as ratings of perceived exertion (RPE) and is based on the workers' subjective feelings about their physical effort, stress, strain, and fatigue. RPE is a practical and cost-effective approach to evaluating workers' level of heat strain in a dynamic environment such as a construction site. It is highly associated with environmental factors such as humidity, air temperature, and wind speed; and physiological indicators such as heart rate, blood pressure, oxygen intake, rate of respiration and fatigue (Yi and Chan 2015). Workers involved in occupations like construction, firefighters and military often expose themselves to extreme weather and wear an uncomfortable protective clothing that is layered, bulky and uniformly designed to every individual which makes the clothing either too tight or too loose in an unbreathable fabric. This impedes the evaporative heat loss process thereby further increasing the body temperature and heat strain. Acclimatization of workers prior to their beginning work is considered important factor for those who work in extreme hot weather conditions (Rowlinson et al., 2014). An acclimatized worker is known to withstand heat for a longer duration with comparatively lower effects of heat on their health. Therefore, acclimatization of workers and their clothing ensemble are some of the individual factors (also classified as personal factors) to be taken into consideration to reduce heat related occupational hazards (Cheung et al.,2000; Nazarian et al., 2021).

4.3.6. Strategies and Welfares Facilities for Outdoor Workers in Hot Weather Conditions

Awareness programs that present occupational heat-related health hazards should be offered to personnel at every level so that they understand the health issues that may be experienced by laborers on construction sites during hot weather (Morris et al., 2020). Rescheduling work activities for cooler parts of the day should be considered as a way to eliminate, or at least reduce, the number and severity of heat-related hazards, and employers should encourage workers to self-pace to avoid becoming exhausted (Leonidas et al., 2022). Workers from other geographical areas that have different weather conditions should be given sufficient time to become accustomed to the heat and employers should ensure that they are assigned less strenuous activities until they have acclimatized to the new weather (Xiang et al., 2015; Tyler et al., 2016; Leonidas et al., 2022). Employers should also provide sufficient work-rest breaks, which will not only protect the workers, but will also improve their productivity and efficiency (Ioannou et al., 2021). Workers should have access to places where they can cool off, such as shady rest areas and clean drinking water. Their personal protective clothing (PPC) should be neither too tight nor too loose and should be made of a light-colored (Ioannou et al., 2021) breathable fabric; cooling vests may also be helpful. Electric fans and evaporative coolers can be used if indoor resting area is made available to the workers. However evaporative coolers are not suggested for smaller rooms. Employers should encourage workers to adopt self-pacing whenever they feel exhausted (Leonidas et al., 2022).

4.4. Research Methodology

This research was conducted in the four phases as presented in Figure 4.2. In the first phase, a comprehensive literature review was performed to understand the challenges faced by construction workers in extreme hot weather conditions. Based on review, a list of potential challenges faced by those who work outdoors were identified and categorized as either physical or mental. Population vulnerable to hot weather conditions were identified and a review on existing standards and regulations for outdoor workers in extreme hot weather was carried out to understand the existing guidelines. The physiological and personal indicators for workers in hot weather conditions were identified. Then a brief review on strategies and welfare facilities for outdoor workers in hot weather were identified from the literature. In phase two, the identified challenges were used to develop an online survey to validate the data revealed by the literature and to identify additional challenges that are faced by the working population in adverse weather conditions. The survey was reviewed and approved by Institutional Review Board (IRB) of the University of Texas at Arlington (UTA), as the survey involved human subjects. The survey was then pilot tested, and the link to the online survey was distributed to more than 500 randomly chosen participants whose contact information (email addresses) was obtained from companies' websites. The distribution was facilitated through the web-based software, Questionpro. Approximately 100 responses were collected and in phase three they were analyzed descriptively and quantitively. The descriptive data analysis involved analyzing the data based on the demographic characteristics of the participants such as age, gender, ethnicity, work experience and the type of construction sector they worked in. The Kruskal-Wallis test was performed for the quantitative analysis, to identify the significant health challenges of workers in hot weather conditions and was based on acclimatization, clothing comfort, heart rate, and blood pressure. The results revealed by the data analysis were discussed in phase 4. The Figure 4.2. below represents the research methodology.

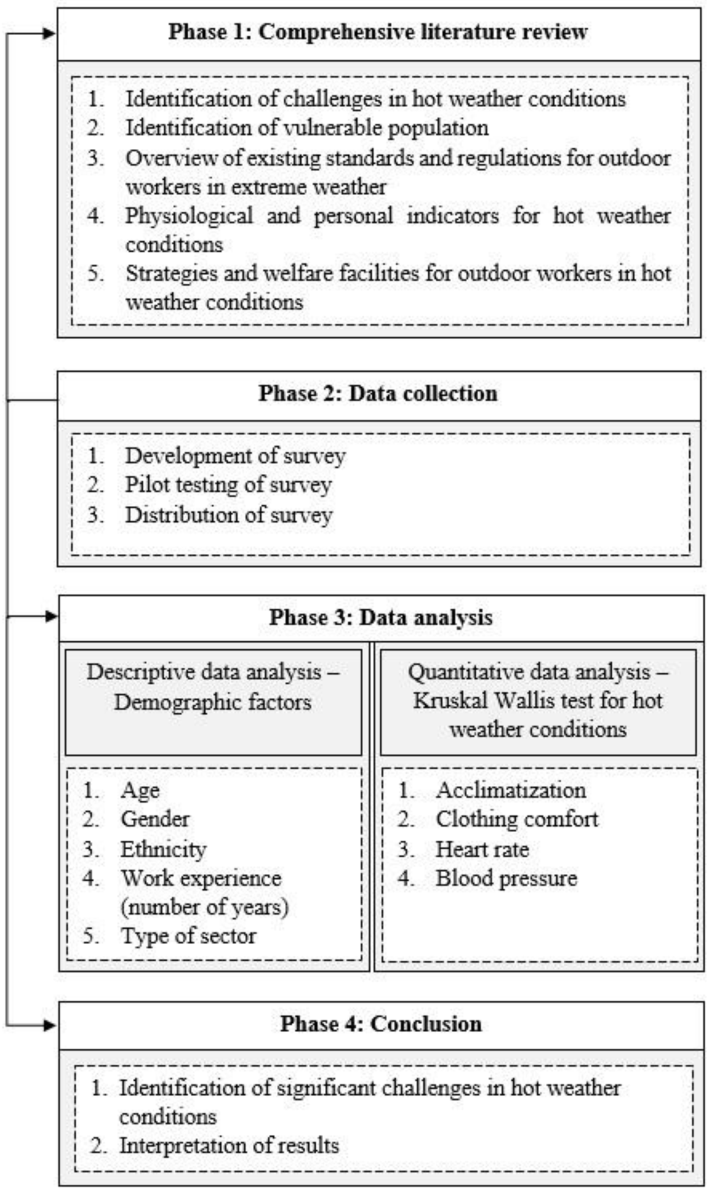


Figure 4. 2. Research Methodology

Kruskal-Wallis test: The Kruskal-Wallis test is a non-parametric test that compares differences in the medians of several groups that do not follow normal distribution. The responses gathered from the survey were analyzed by the Kruskal-Wallis test, as the questions were based on a seven-point Likert scale. The test statistic for the Kruskal-Wallis test is shown in Equation (1) below.

$$H = \frac{12}{n(n+1)} \sum_{i=1}^{k} \frac{r_i^2}{n_i} - 3(n+1) \qquad (1)$$

In the above Kruskal-Wallis equation, (*n*) represents the total number of observations, (*K*) represents the number of groups, (*r*) represents the rank of each group, and (n_i) represents the number of observations in each group (*i*) (Montgomery and Runger 2003). The challenges faced by the workers in hot weather conditions were tested based on the workers' levels of acclimatization, clothing comfort, heart rate, and blood pressure. Clothing comfort and acclimatization are considered personal indicators of health challenges; heart rate and blood pressure are physiological indicators The application of Kruskal-Wallis test according to the perception of respondents revealed that heat-related symptoms like dehydration, sweating, and physical fatigue were influenced based on the degree to which the workers have been acclimatized to their working environment. Physical health challenges like respiratory issues and physical fatigue were indicated by change in their heart rate; and sweating, heat cramps, and edema were uniformly experienced irrespective of level of comfort of the workers' clothing. The hypothesis used for the study is represented in Table 4.1. below.

Table 4. 1. Research Hypothesis

Workers' Characteristics	Statistical Tests	Hypothesis
Based on workers' acclimatization: Workers who are used to local weather conditions and workers not used to local weather conditions	Kruskal-Wallis test	Null Hypothesis (H_o): Health challenges of working in extreme hot weather conditions do not vary based on workers' acclimatization. Alternate hypothesis (H_a): Health challenges of working in extreme

		hot weather conditions vary based on workers' acclimatization.
Based on workers' heart rate: Workers experiencing an abnormal heart rate and workers experiencing a normal heart rate	Kruskal-Wallis test	Null Hypothesis (H_o): Health challenges of working in extreme hot weather conditions do not vary based on workers' heart rate. Alternate hypothesis (H_a): Health challenges of working in extreme hot weather conditions vary based on workers' heart rate.
Based on workers' protective clothing: Workers with uncomfortable protective clothing and workers with comfortable protective clothing	Kruskal-Wallis test	Null Hypothesis (H_o): Health challenges of working in extreme hot weather conditions do not vary based on discomfort caused due to protective clothing. Alternate hypothesis (H_a): Health challenges of working in extreme hot weather conditions vary based on discomfort caused due to protective clothing.
Based on workers' blood pressure: Workers with abnormal blood pressure and workers with normal blood pressure levels	Kruskal-Wallis test	Null Hypothesis (H_o): Health challenges of working in extreme hot weather conditions do not vary based on workers' blood pressure. Alternate hypothesis (H_a): Health challenges of working in extreme hot weather conditions vary based on workers' blood pressure.

4.5. Data Collection

4.5.1. Survey Development

The survey was comprised of 25 questions that were grouped in several subcategories related to (1) demographics; (2) the respondent's perception of the physical and (3) mental challenges of working in hot weather conditions; (4) personal lifestyle choices such as clothing comfort, drinking habits, and tobacco use; and (5) the nature of their working environment (such as indoor, outdoors, or a combination of the two). Only about 19% of the respondents worked indoors. The questions pertaining to demographics were designed to identify characteristics such as age, level of education, experience in the industry, specialization, and any pre-existing medical conditions. Behavioral questions were designed to identify personal habits such as alcohol and tobacco use and to determine their level of awareness of the hazards of working in extremely hot weather. The survey was developed using an online tool known as Questionpro and was distributed through email. The criteria for the participants were that they had to be older than 18 and be employed in the construction sector; they were not compensated for taking part in the study. The participants were randomly selected from private construction firms, and their contact information was obtained through the company website. Approximately 100 responses were received after multiple rounds of distribution and follow-up emails.

4.6. Descriptive Data Analysis

The survey was distributed nationally, and the 100 responses were descriptively analyzed to understand the demographic characteristics of the respondents. Approximately 87% of the participants were males and 13% were females, 60% were older than 50, 12% were between the ages of 31 and 40, and 28% were between the ages of 21 and 30. The responses to the question on ethnicity revealed that 63% were Caucasians. Approximately 45% of them worked in the commercial sector, 29% in the infrastructure sector. Table 4.2. below represents the demographic information of the survey participants.

Table 4. 2. Descriptive Analysis of Survey Participants

Characteristics of Participants	Percentage
Gender	Male – 87% Female – 13%
Ethnicity	Caucasians – 63% Other – 37%
Age	Over 40 years – 60% Between 31 – 40 years – 12% Between 21 – 30 years – 28%
Work experience	Over 25 years – 36% Less than 5 years – 23% Other – 41%
Type of sector	Commercial sector – 45% Infrastructure sector – 29% Other - 26%

The participants' roles varied from managerial positions, including construction project manager, project engineer, corporate safety director, design engineer, and associate vice president, to specialty positions that included masonry foreman, roofing expert, ironworker, plumbers, and those who worked with concrete. Approximately 10% of the respondents held managerial positions or other positions of authority, as the authors felt that it was important to elicit their opinions. About 36% of the respondents had worked for more than 25 years in the construction industry, while 23% had less than 5 years' experience.

4.7. Quantitative Data Analysis

4.7.1 Results and Discussion

4.7.1.1. Identifying Significant Challenges in Hot Weather Based on Workers' Acclimatization

The responses collected from the survey were statistically analyzed using the Kruskal-Wallis test, as the majority of the survey questions were based on the seven-point Likert scale. The Kruskal-Wallis test was performed for hot weather conditions, using various factors. The p-value for the hot weather conditions based on workers' acclimatization characteristics are represented in Table 4.3.

Table 4. 3. P-values Testing the Significance of Challenges based on Workers' Acclimatization

Category	#	Factors/ Challenges	P-Values based on workers' acclimatization
Physical challenges in hot weather conditions (PHW)	PHW1	Discomfort due to personal protective clothing	0.044**
	PHW2	Dehydration	0.034**
	PHW3	Major accidents in workplace	0.257
	PHW4	Minor wounds/injuries	0.108
	PHW5	Respiratory issues	0.094
	PHW6	Excessive sweating	<0.001**
	PHW7	Dermatological problems	0.024**
	PHW8	Physical fatigue	0.032**
	PHW9	Heat edema	0.065
	PHW10	Heat cramps	0.075
	PHW11	Kidney disease	0.039**
	PHW12	Increased blood sugar levels	0.062
Mental challenges in hot weather conditions (MHW)	MHW1	Frequent mood fluctuations	0.049**
	MHW2	Inability to concentrate	0.019**
	MHW3	Lack of control of temper	0.003**
	MHW4	Ability to self-pace	0.014**
	MHW5	Need for longer breaks	0.085

Note: ** denotes 95% level of confidence.

The data analysis indicates that the survey participants believe that 6 of the 12 physical health challenges experienced by those who work outdoors in extreme heat are influenced by the level of worker acclimatization. This supports the findings of the existing literature (NIOSH 2018) that the bodies of those who are acclimatized to the weather regulate fluids more efficiently and lose fewer electrolytes. Workers not accustomed to local weather conditions are likely to experience more physical fatigue and dehydration (Tian et al., 2011), as their thirst mechanism is compromised, and they do not sweat as freely. Acclimatization also helps improve hydration, which can prevent workers from experiencing chronic kidney disease (Kenny et al., 2018).

Acclimated workers' lower core body temperature increases their stamina and allows them to work for longer periods of time without taking a break (Foster et al., 2020). However increased sweating, even in acclimated workers wearing uncomfortable protective clothing, can result in dermatology problems such as heat rash, often known as prickly heat, which occurs when the pores of sweat glands are clogged (Carroll 2002). Protective clothing made of breathable fabric mitigates this problem.

Four of the five mental challenges (frequent mood fluctuations, inability to concentrate, lack of control of temper, and ability to self-pace) are common among those working in hot weather. Allowing workers to acclimate to new temperatures can help them manage their emotional health and will result in their having less mental fatigue, improved concentration, and better control over their temper. From Table 4.3, it is evident that the ability to self-pace is different in workers who are acclimated to their environment than in workers who are not. Non-acclimatized workers experience symptoms of heat stress whereas acclimatized workers can perform activities for longer durations and be more productive as their physiological responses, as well as their mental and emotional health, are better.

4.7.1.2. Identifying Significant Challenges in Hot Weather Based on Heart Rate

Heart rate is an important physiological indicator of heat strain. The responses from the survey were analyzed based on workers' perceptions of their heart rate during physical exertion in extreme hot weather conditions, and the significant challenges, based on the results of the P-value, are shown in Table 4.4.

Table 4. 4. P-values Testing the Significance of Challenges based on Heart Rate

Category	#	Factors/ Challenges	P-Values based on heart rate
Physical challenges in	PHW1	Discomfort due to personal protective clothing	0.147

hot weather conditions (PHW)	PHW2	Dehydration	0.003**
	PHW3	Major accidents in workplace	0.976
	PHW4	Minor wounds/injuries	0.126
	PHW5	Respiratory issues	0.026**
	PHW6	Excessive sweating	0.002**
	PHW7	Dermatological problems	<0.001**
	PHW8	Physical fatigue	<0.001**
	PHW9	Heat edema	0.003**
	PHW10	Heat cramps	<0.001**
	PHW11	Kidney disease	<0.001**
	PHW12	Increased blood sugar levels	0.009**
Mental challenges in hot weather conditions (MHW)	MHW1	Frequent mood fluctuation	0.002**
	MHW2	Inability to concentrate	0.009**
	MHW3	Lack of control on temper	0.004**
	MHW4	Ability to self-pace	0.027**
	MHW5	Need for longer break duration	0.032**

Note: ** denotes 95% level of confidence.

Nine of the twelve physical challenges (dehydration, increased sweating, respiratory issues, dermatological problems, physical fatigue, heat edema, heat cramps, kidney disease and elevated blood sugar levels) were identified as being significant in hot weather conditions, based on the results from the Kruskal-Wallis test. The results from Table 4.4 show that the perceptions of the survey participants corroborate with the literature's stance that a rapid heart rate results in increased sweating and physical fatigue and could be the reason that the heart has to pump more blood to cool down the body in extreme heat.

Abnormal variations in heart rate indicate that workers performing in hot weather are experiencing excessive sweating, physical fatigue, and heat cramps that could lead to severe health hazards such as kidney disease, heat edema, and elevated blood sugar levels when they are ignored. Respiratory issues like asthma which often results in coughing, wheezing and breathlessness are also indicated by variations in the heart rate in hot weather. All five of the mental challenges were deemed significant in hot weather conditions. Workers who are unable to control their temper and exhibit frequent mood fluctuations may exhibit higher heart rates than their co-workers who are calmer and happier. Performing in a hot environment also makes the workers mental state more drained or exhausted as they need to perform physically laborious activities in unfavorable weather conditions. Workers need to be provided with an efficient work-rest regimen so that they can regain their normal heart rate after strenuous activity.

4.7.1.3. Identifying Significant Challenges in Hot Weather Based on Blood Pressure

Blood pressure in another physiological indicator of heat strain, and the challenges identified based on blood pressure, using the Kruskal-Wallis test, are presented in Table 4.5. Medically monitoring changes in blood pressure can be used to identify individuals who are experiencing heat strain. The results of the Kruskal-Wallis test pertaining to the blood pressure of those working in extremely hot weather revealed that nine of the twelve challenges (dehydration, minor injuries, increased sweating, dermatological problems, physical fatigue, heat edema, heat cramps, kidney disease, and elevated blood sugar levels) were significant. Fluctuations in blood pressure indicate that the body is experiencing heat-related symptoms. A sudden drop or change in blood pressure occurs when the body experiences heat cramps, and heat edema, which are due to the storage of heat in specific locations of the body. Table 4.5. below reveals the results of P-values based on blood pressure.

Table 4. 5. P-values Testing the Significance of Challenges based on Blood Pressure

Category	#	Factors/ Challenges	P-Values based on blood pressure
Physical challenges in hot weather conditions (PHW)	PHW1	Discomfort due to personal protective clothing	0.068
	PHW2	Dehydration	0.001**
	PHW3	Major accidents in workplace	0.320
	PHW4	Minor wounds/injuries	<0.001**
	PHW5	Respiratory issues	0.074
	PHW6	Excessive sweating	0.043**
	PHW7	Dermatological problems	0.002**
	PHW8	Physical fatigue	0.005**
	PHW9	Heat edema	0.007**

	PHW10	Heat cramps	0.004**
	PHW11	Kidney disease	<0.001**
	PHW12	Increased blood sugar levels	<0.001**
Mental challenges in hot weather conditions (MHW)	MHW1	Frequent mood fluctuation	<0.001**
	MHW2	Inability to concentrate	0.024**
	MHW3	Lack of control on temper	0.009**
	MHW4	Ability to self-pace	0.245
	MHW5	Need for longer break duration	0.058

Note: ** denotes 95% level of confidence.

Based on the perceptions of the survey participants, three of the five mental challenges (frequent mood fluctuations, inability to concentrate, and lack of temper control) are believed to be influenced by blood pressure; the remaining two (inability to concentrate and lack of temper control) are believed to lead to unsafe working conditions on construction sites. Medically monitoring blood pressure levels and identifying workers with frequent fluctuations can protect them from being further exposed to health and work hazards Regardless of blood pressure levels, however, it is evident that workers need to pace themselves so that they are able to work longer, more competently, and safer.

4.7.1.4. Identifying Significant Challenges in Hot Weather Based on Workers' Clothing

In hot weather conditions, five of the eleven physical health challenges (major accidents at the workplace, minor injuries, physical fatigue, excessive sweating and dermatological problems) were found to be significant based on workers clothing comfort. Inappropriate PPC makes workers uncomfortable, and when combined with extremely hot weather, it creates fatigue and increases the number of workplace injuries and accidents. Clothing that is too tight does not easily support in heat dissipation, due to which the entrapped heat increases, resulting in heat stress and may indirectly contribute to dehydration. The combination of environmental heat, metabolic heat and entrapped heat that is not able to dissipate through sweat fatigues workers and hampers their productivity. Table 4.6. below reveals the results of P-values obtained from Kruskal-Wallis test based on workers' clothing.

Table 4. 6. P-values Testing the Significance of Challenges based on Clothing

Category	#	Factors/ Challenges	P-Values based on clothing
Physical challenges in hot weather conditions (PHW)	PHW1	Dehydration	<.001**
	PHW2	Major accidents in workplace	0.047**
	PHW3	Minor wounds/injuries	0.006**
	PHW4	Respiratory issues	0.466
	PHW5	Excessive sweating	0.002**
	PHW6	Dermatological problems	0.021**
	PHW7	Physical fatigue	0.011**
	PHW8	Heat edema	0.076
	PHW9	Heat cramps	0.942
	PHW10	Kidney disease	0.777
	PHW11	Increased blood sugar levels	0.938
Mental challenges in hot weather conditions (MHW)	MHW1	Frequent mood fluctuation	0.034**
	MHW2	Inability to concentrate	0.091
	MHW3	Lack of control on temper	0.006**
	MHW4	Ability to self-pace	0.199
	MHW5	Need for longer break duration	0.228

Note: ** denotes 95% level of confidence.

Frequent mood fluctuations and lack of temper control are also observed in workers with uncomfortable PPC. One solution is to provide workers with cooling vests, as they do not inhibit sweating or movement, and can make them feel better. The results of the P-values indicate that the above-mentioned challenges in hot weather conditions also differ based on the comfort of protective clothing used by the workers. Workers should be provided with comfortable and breathable fabric in hot weather conditions. Planning strategies based on clothing comfort are effective and helpful in circumstances when engineering controls are not applicable.

4.8. Conclusion

Construction workers are most affected by temperature extremes in hot weather conditions, and it is important for employers to ensure their safety. Unfortunately, most construction companies lack adequate policies to protect the health of those working on construction sites in extremely hot temperatures. The majority of literature studies focus on the outdoor working population in general rather than specifically on construction workers who are exposed to extreme heat for long periods of time. This paper, therefore, aimed to identify the challenges faced by construction workers in hot weather conditions and categorize them as either physical or mental health challenges. Existing standards governing workers performing in extreme hot weather conditions were briefly discussed, and a questionnaire survey was developed and distributed to workers in the construction industry go gain additional and current data.

The 100 responses received from the survey were gathered and statistically analyzed, based on the workers' acclimatization, heart rate, blood pressure, and personal protective clothing. Minor workplace injuries and major accidents occur irrespective of the heart rate, but it is an indicator of physical fatigue and respiratory problems. The results infer that challenges such as dehydration, sweating, and physical fatigue are influenced by whether the workers are acclimatized to their working environment. Increased sweating, heat edema and heat cramps were common among workers in hot weather conditions based on the comfort of their clothing. The conclusions drawn from this study support the following basic tenets of the existing literature: (1) it is important for workers to be acclimatized to the weather conditions on construction sites, (2) clothing properties influence the challenges faced by workers in extreme hot weather, and (3) monitoring workers' heart rates and blood pressure can help prevent heat-related illnesses. An important limitation of this study is that the results are solely based on an empirical approach and the addition of clinical aspects would increase its evidence, focus and usefulness. The findings obtained from the survey of this study will be used to develop a model that can predict the short- and long-term health challenges faced by those working in extreme heat and will be the basis for recommendations of ways that construction practitioners can protect their workers' health and safety on construction sites. The results obtained from this study will also be useful in developing a physiological monitoring program that can be used, when WBGT is not possible, to identify the challenges that workers experience in hot weather conditions so that preventative measures can be developed to protect them.

CHAPTER 5

IMPACT ANALYSIS OF HEAT ON PHYSICAL AND MENTAL HEALTH OF CONSTRUCTION WORKFORCE

5.1. Abstract

More than one-third of all occupational deaths are heat-related, and it is probable that many more non-fatal injuries occur from overexposure to heat but are not reported. Prolonged exposure to excessive heat results in construction workers suffering from a wide range of physical and mental health issues that can lower their productivity and cause an increased number of accidents. To investigate how heat impacts their physical and mental health, a survey was developed and distributed through an online platform to construction workers who work in various sectors, including transportation. The 100 responses received revealed that excessive heat affects workers both mentally (difficulty concentrating, irritableness, and frequent mood swings) and physically (fatigue, level of hydration, and kidney disease). Perspiration also plays a role in how a worker is impacted by the heat, as higher blood sugar levels and hypertension are more common among workers who perspire less. Breaks, continuous hydration, sufficient cooling facilities, and acclimatization of workers are some of the factors that can reduce heat-related injuries and accidents on construction sites.

Keywords: Health challenges, Hot weather, Worker habits, Outdoor workers, Extreme weather.

5.2. Introduction

Physiological responses are significantly impacted by excessive heat stress and result in reduced productivity and an increase in the number of workplace injuries and fatalities (Yi and Chan 2017). This is an important area of research for the construction industry, where intervention is vital because of the high frequency of fatal and non-fatal work-related injuries (Hoonakker et al., 2005;

Karthick et al., 2022d). The prevalence of heat-related deaths each year has always been frightening (Chan et al., 2012), but between 2000 and 2010, 359 people died from heat-related occupational deaths, a rate of 0.22 per million employees, per year (Gubernot et al., 2015). Prolonged exposure to high temperatures and humidity may result in heat stroke, heat cramps, heat exhaustion and heat syncope (Inaba and Mirbod 2007), and accidents occur more frequently when workers' health is compromised. Physiological reactions to heat stress are not uniform, as workers exhibit different responses, depending upon how sensitive and vulnerable they are to it (Inaba and Mirbod 2007). This makes it necessary to examine the impacts of heat on various groups of workers based on their demographic characteristics, hydration levels, heat tolerance and acclimatization (Kemala et al., 2018). Heat stress causes the human body to respond in two ways. One of the mechanism is through vasodilation, where the blood flow gets redistributed towards the skin and improves the heat transfer between muscles and the cutaneous membranes. The other mechanism involves releasing the sweat onto the skin, which reduces the core body temperature (Ebi et al., 2021). This continuous process is also indicated by physical responses like dehydration, physical fatigue, mental fatigue, etc. (Ebi et al., 2021; Rouhanizadeh and Kermanshachi 2021). During this mechanism, workers with pre-existing medical conditions, such has heart problems, may exhibit negative effects (Ebi et al., 2021). Excessive sweating can cause dehydration and is also related to kidney disease (Ebi et al., 2021). How workers are impacted by prolonged hot weather is also an indication of their personal habits, as drinking alcohol and smoking tobacco are detrimental to their thermoregulatory functions in extreme weather conditions (Yi and Chan 2013). The thermal environment is one of the factors that can reduce worker productivity and impair mental performance (Srinavin and Mohamed 2003; Pamidimukkala et al., 2021). Effective safety standards and regulations are important in reducing workplace accidents and in improving workers' health and jobsite productivity (Zahoor et al., 2016), even in extremely hot weather. The Occupational Safety and Health Administration (OSHA) has provided several management strategies for employers to use to protect their workers from heat-related deaths, but there is little evidence that they have been implemented to a significant extent (Arbury et al., 2016). It is also vital to develop strategies for workers who are more susceptible to heat stress.

This paper aims to address the above concerns by analyzing how heat impacts construction workers mentally and physically. To this end, a survey was developed and distributed to workers in the construction industry, and the data collected from the survey were analyzed based on workers' drinking habits, their level of perspiration, and their work environment. The outcomes of this survey will help future researchers and professionals develop management strategies that will allow construction workers to remain safe and healthy while working under hot weather conditions. The results of this survey can be used in the future to develop a model that can predict how workers' short- and long-term health will be affected by their working environment, based on the intensity of their heat exposure.

5.3. Literature Review

5.3.1. Impact of Hot Weather Condition on Outdoor Working Population

Outdoor workers often labor in high heat for prolonged periods of time without taking adequate precautionary measures and suffer from symptoms of heat stress. The core body temperature of humans varies between 97.7 to 99.5 degrees Fahrenheit, and when individuals are exposed to extremely unfavorable temperatures, their natural physiology tries to thermoregulate the imbalance (Cheung et al., 2016). Symptoms such as sweating, increased heart rate, and physical fatigue exacerbate when the body is unable to maintain its core body temperature (Yasmeen et al., 2020). Heat stress is defined as the total ambient and metabolic heat loads that increase an individual's core body temperature (CBT) and may result in physiological dysfunctions (El-Shafei et al., 2018; Karthick et al., 2022h). Some of the heat-related illnesses are edema, muscle cramps, and prickly heat (a skin rash and redness due to hot weather). Workers may also experience heat syncope, a condition that can include fainting and dizziness caused by low blood pressure and prolonged standing in elevated temperatures (Atha 2013; Adepu et al., 2022). Heat-related illnesses may result in acute kidney disease, which is the outcome of unreplenished fluids that were lost in sweat and dehydration. An increase in body temperature may also result in the central nervous system malfunctioning and/or damage to organs, respiratory issues, and cardiovascular problems (Tseng et al., 2020; Karthick et al., 2021). A timeseries study conducted by Tseng et al., 2020 revealed that an increase in the number of hot weather days is associated with increased morbidity and an increase in the number of emergency room visits (Tseng et al., 2020).

Excessive sweating is a vital indicator for diagnosing heat-related illnesses. Excessive sweating while performing a physically demanding job in extremely hot weather leads to inability to focus on tasks, distress, discomfort, and behavioral fluctuations that eventually result in injuries and accidents (El-Shafei et al., 2018). A study conducted by Dutta et al. (2015) illustrated the effects of heat stress on construction workers in India by revealing that the majority of the workers reported intense sweating, dark colored urine, and dry mouth. Headaches, loss of coordination, tingling sensation in hands, and dizziness were also symptoms experienced by the workers (El-Shafei et al., 2018). A questionnaire survey conducted by Inaba and Mirbod to compare the subjective symptoms experienced in hot weather by traffic control workers and construction workers revealed that 63.7% of the workers reported feeling thirsty at work, 42.2% reported being easily fatigued" 13.2% reported headaches, and 11.8% reported dizziness (Inaba and Mirbod 2007; El-Shafei et al., 2018). Some of the workers who are more susceptible to heat-related illnesses and injuries are over 55 years of age (Xiang et al., 2014); Hispanic men and women (Acharya et al., 2018); expatriate workers, and others who are not acclimated to local weather; underweight/obese workers (Acharya et al., 2018); and workers who specialize in roofing, bar bending, and scaffolding (Chang et al., 2009; Wong et al., 2014). According to the research, women are more likely to face occupational stress and mental health issues than males (Pamidimukkala & Kermanshachi 2021; Pamidimukkala & Kermanshachi 2022b). Other risk factors for heat-illnesses include alcohol consumption, comorbid medical conditions such as diabetes, skin disorders, and cardiovascular diseases (Leiva and Church 2020).

5.4. Research Methodology

An extensive literature review was conducted to understand the current body of knowledge on the effects of hot weather on the outdoor working population. Keywords such as "worker health," "outdoor workers," "hot weather," "construction workers," "physical challenges," and "mental challenges" were entered into various scholarly search engines such as Google Scholar, PubMed, Directory of Open Access Journals (DOAJ), and SpringerLink. In the second step, workers vulnerable to heat stress were identified based on information found in the literature search. In the third step, a questionnaire survey was developed, based on the various heat-related health effects identified from literature review, and was distributed through the online platform, "QuestionPro" to those in the construction sector. The participants' contact information was found through various professional platforms. In the fourth step, statistical analysis was performed on the data collected from the 100 responses that were received. The results of the statistical tests were then interpreted and discussed. Figure 5.1. illustrates the research methodology.

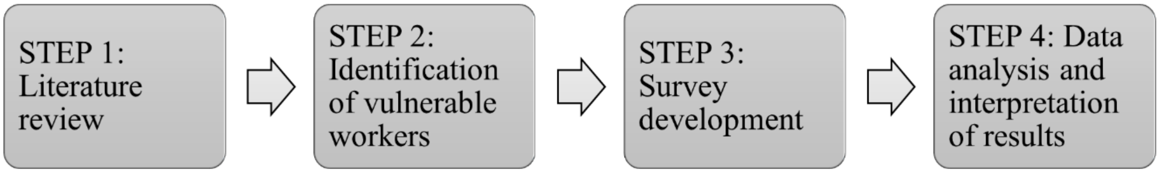


Figure 5. 1. Research Methodology

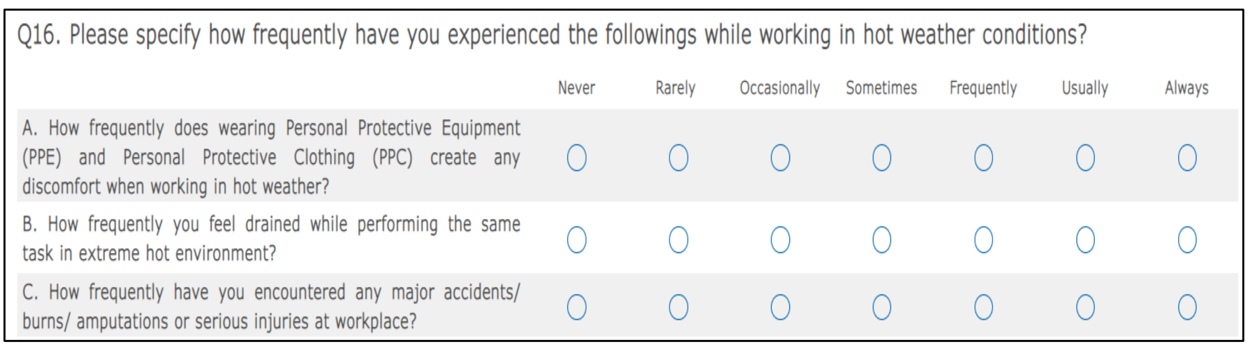
Since the questionnaire involved Likert scale data (ordinal data type), the Kruskal-Wallis test, a non-parametric testing method, was adopted, as it compares the differences between the medians of various groups. The hypothesis developed for this study is represented in Table 5.1.

Table 5. 1. Research Hypothesis Adopted for this Study

Workers' characteristics	Statistical tests	Hypothesis
Based on workers' drinking habits: Workers consuming alcohol and workers not consuming alcohol	Kruskal-Wallis test	Null hypothesis (H_o): Health challenges of working in hot weather do not vary based on workers' drinking habits. Alternate hypothesis (H_a): Health challenges of working in hot weather vary based on workers' drinking habits.
Based on workers' perspiration: Workers experiencing excessive sweating and workers not experiencing sweating	Kruskal-Wallis test	Null hypothesis (H_o): Health challenges of working in hot weather do not vary based on workers' perspiration status. Alternate hypothesis (H_a): Health challenges of working in hot weather vary based on workers' perspiration status.
Based on workers' work environment: Those working indoors and those working outdoors	Kruskal-Wallis test	Null hypothesis (H_o): Health challenges of working in hot weather do not vary based on workers' work environment. Alternate hypothesis (H_a): Health challenges of working in hot weather vary based on workers' work environment.

5.5. Survey Development

The survey was developed based on the existing body of knowledge and with the help of the online tool, QuestionPro, and was distributed through an online platform. Individuals were invited by email to participate in the survey and were given a brief summary of the research. Only workers in the construction sector or one related to the construction industry who were above the age of 18 were eligible to participate. The survey questions were classified into various categories, such as demographic questions that helped identify the worker's background, questions that provided information about physical or mental challenges, and a few behavioral questions that were designed to identify the worker's personal habits. A sample question from the survey is shown in Figure 5.2.


Q16. Please specify how frequently have you experienced the followings while working in hot weather conditions?

	Never	Rarely	Occasionally	Sometimes	Frequently	Usually	Always
A. How frequently does wearing Personal Protective Equipment (PPE) and Personal Protective Clothing (PPC) create any discomfort when working in hot weather?	○	○	○	○	○	○	○
B. How frequently you feel drained while performing the same task in extreme hot environment?	○	○	○	○	○	○	○
C. How frequently have you encountered any major accidents/ burns/ amputations or serious injuries at workplace?	○	○	○	○	○	○	○

Figure 5. 2. Sample Survey Question

5.6. Data Analysis

5.6.1. Descriptive Analysis

The 100 responses were descriptively analyzed based on demographic characteristics and showed that 86% of the respondents were males, 63% were Caucasian, and 60% were above 40 years of age. The responses to the questions pertaining to number of years the respondents had worked in the construction industry revealed that 36% had more than 25 years of experience and 23% had less than 5 years of experience; 45% worked in the commercial construction sector, 29% in the infrastructure sector, 9% worked in heavy construction, and 9% worked in the residential sector. The survey showed that 76% of the participants were from places with a lot of hot weather. Table 5.2 provides a brief descriptive analysis of the participants, based on their demographic characteristics.

Table 5. 2. Descriptive Analysis of Survey Participants

Characteristics of participants	Percent in sample
Gender	Male – 86% Female – 14%
Ethnicity	Caucasians – 63% Other – 37%
Age	Over 40 years – 60% Between 31 – 40 years – 12% Other – 28%
Work experience	Over 25 years – 36% Less than 5 years – 23% Other – 41%
Weather conditions	Hot weather – 76% Other – 24%
Construction sector	Commercial sector – 45% Infrastructure sector – 29% Other - 26%

The Kruskal-Wallis test was performed based on workers' personal habits, their level of perspiration, and their work environment, and the output is presented in Table 5.3 below. Of the 16 variables, 12 were significant for p-values based on workers' drinking habits and perspiration levels; 6 were significant for workers, based on their working environment.

Table 5. 3. Significance Test for Workers in Hot Weather Conditions Based on Workers' Habits, Perspiration and Work Environment

ID	Factors/ Challenges	P-Values based on workers' drinking habits	P-Values based on workers' perspiration	P-Values based on workers' environment

1	Discomfort due to personal protective clothing	0.742	0.009**	0.314
2	Dehydration	0.024**	0.001**	0.086*
3	Physical injuries/accidents in workplace	0.010**	0.453	0.061*
4	Respiratory challenges such as asthma	0.006**	0.061*	0.047**
5	Dermatology problems like skin rash, redness, skin irritation	0.256	0.001**	0.058*
6	Increased heart rate	0.047**	0.001**	0.044**
7	Physical fatigue	0.002**	0.001**	0.020**
8	Heat edema	0.100*	0.297	0.814
9	Heat cramps	0.527	0.006**	0.015**
10	Kidney disease	0.013**	0.569	0.050*
11	Increased blood sugar	0.020**	0.033**	0.055*
12	Hypertension	0.019**	0.042**	0.003**
13	Frequent mood fluctuations	0.033**	0.001**	0.536
14	Inability to concentrate	0.002**	0.001**	0.012**
15	Lack of control of temper	0.019**	0.001**	0.560
16	Need for longer breaks	0.013**	0.046**	0.752

Note: * denotes 90% level of confidence and ** denotes 95% level of confidence.

5.6.2. Results and Discussion

5.6.2.1. Interpretation of the Results – Based on Workers' Drinking Habits

As shown in Table 5.3. the results obtained from the Kruskal-Wallis test show that the effects of hot weather such as dehydration, respiratory issues, physical fatigue, heat edema, kidney disease, high blood sugar, and hypertension vary, based on the workers' alcohol consumption, as do some of mental challenges such as frequent mood changes, inability to concentrate, feeling irritable, and the need for longer breaks. It was observed that discomfort caused by personal protective clothing (PPC), dermatology issues, and heat cramps are same for all the groups.

5.6.2.2. Interpretation of the Results – Based on Workers' Perspiration

The results of the statistical analysis shown in Table 5.3. indicate that challenges such as discomfort due to personal protective clothing, dehydration, skin rash, increased heart rate, physical fatigue, heat cramps, increased blood sugar levels, and hypertension are different for workers who adequately sweat and workers who do not. Mental challenges such as the inability to concentrate, lack of temper control, and mood changes also vary across the groups. However, some of the effects of hot weather such as physical injuries in the workplace, heat edema and kidney disease are the same across workers groups, based on their perspiration.

5.6.2.3. Interpretation of the Results – Based on Workers' Environment

The P value from Table 5.3. indicates that physical health challenges such as respiratory issues, rapid heartrate, physical fatigue, heat cramps, and hypertension are different for those who work outdoors and those who work indoors, as is the ability (or inability) to concentrate. Discomfort due to PPC, heat edema, frequent mood changes and lack of temper control are the same among outdoor and indoor workers.

5.7. Conclusion

The increasing number of hot weather days caused by climate change has increased the number of work-related heat injuries and resulted in various physical and mental health challenges that are outlined and classified in this research paper. Some workers are more prone to suffering ill effects from hot weather than others, and the health-related issues that play significant roles in this, such as dehydration, asthma, physical fatigue, hypertension, and alcohol use, were also identified. Perspiration is considered one of the indicators for heat related illnesses, as the results revealed that the majority of the challenges such as dehydration, skin rash, rapid heart rate, physical fatigue, heat cramps, and hypertension vary based on how profusely workers perspire. Some of the physical challenges such as fatigue, rapid heart rate, and heat cramps also vary, based on the workers' environment. The findings of this study will assist in the development of safety strategies for workers in hot weather conditions and can be used to develop a model for predicting workers short- and long- term health issues based on their exposure to hot weather conditions.

CHAPTER 6

ANALYSIS OF CONSTRUCTION WORKERS' HEALTH AND SAFETY IN COLD WEATHER CONDITIONS

6.1. Abstract

Extreme cold weather conditions affect construction workers health and impedes the progress of construction work. Individuals exposed to extremely cold weather face performance-related challenges, safety hazards and disorders like frostbite, hypothermia, trench foot, necrosis, and chilblains. Therefore, this article identified and analyzed the challenges experienced by construction workers in extreme cold weather conditions. A questionnaire was created and circulated through the online platform Questionpro to achieve this goal. There was a total of 111 responses. The Kruskal-Wallis test was used to examine the issues identified through the responses. The quantitative analysis for cold weather conditions was done using physiological indicators like heart rate and personal indicators like worker comfort and acclimation. Physical obstacles such as hypothermia and respiratory issues induced by cold weather conditions in the workplace were found to be distinct among workers based on heart rate and garment comfort, according to the findings of the study. Most mental issues, such as poor concentration and frequent mood swings, were different among workers based on their level of acclimatization and heart rate in cold weather conditions. Ensuring that workers wear sufficient layers of clothing, heated gloves and adopting technologies like infrared heaters are some of the strategies to be implemented to protect workers from cold weather challenges. This article further addresses existing practices and legislation controlling construction workers' safety in extreme cold weather conditions. The findings of this article will assist construction industry professionals in properly managing and ensuring worker safety in harsh cold weather circumstances.

Keywords: Worker Safety, Worker Health, Health Challenges, Cold weather, Extreme Weather.

6.2. Introduction

Epidemiological studies indicate that effects of cold weather conditions on human health is more indirect compared to effects caused due to hot weather conditions (Bonafede et al., 2016). During the year 2017, there were an average of 1706 cold-related workplace injuries according to the Bureau of Labor Statistics (BLS, 2019). Cold related mortalities are more gradual, and the onset of cold weather health consequences take longer duration of time whereas effects of hot weather conditions are more rapid. There are only limited studies focusing on the effects of cold weather on human health compared to studies focusing on health challenges in hot weather conditions, especially in outdoor working populations. (Allen and Sheridan 2018; Sugg et al., 2019). Therefore, outdoor workers' health challenges in extreme cold weather conditions need to be explored to protect their health and reduce workplace accidents (Kiefer et al., 2016).

In cold weather conditions, exposed population might undergo cold stress, frostbite, hypothermia, cardiac strain, physical fatigue and change in respiration rate (Angelova 2017). Working in extreme temperatures also results in reduced cognitive function, mental fatigue and lowered concentration levels in workplace, thus increasing the number of accidents and compromising workplace safety (Kiefer et al., 2016). Cold working conditions causes engineering problems as well. These may include additional efforts in the design and construction processes, impacts maintenance workers, visibility hazards for equipment operators in workplace due to poor visibility leading to difficult operations in winter weather conditions (Giudici et al., 2020; Claros et al., 2021; Ameen et al., 2022). Some of the winter operations that involve workers to perform manual work includes site clearance activities (Perkins and Bennett 2018), excavation activities (Colgan and Arenson 2013) operating equipment that involve vibration mechanism, site development works (Perkins and Bennett 2018) that require intense labor activities. The above-mentioned operations require employees to performing in cold weather risking their health. Also, health effects of cold exposure cannot be uniform. There could be worker population who are more vulnerable when exposed to cold weather. Several studies are available that discussed about the vulnerable population when exposed to extreme heat. However, the literature studies focusing on vulnerable populations in cold weather conditions are comparatively less explored. Also, literature studies focusing on regulations and standards for outdoor workers in cold weather conditions are scant.

The influence of extreme weather on human health could be assessed using physiological parameters along with environmental indices. Physical signs such as increased heart rate, blood pressure levels, and oxygen intake, as well as personal indicators such as garments, age, drinking habits, and workers' acclimatization, all influence the physiological responses generated during extreme weather conditions (Pilch et al., 2014; Yi and Chan 2015; Austad et al., 2018). Humidity, temperature, wind speed, pollution, and radiation are all environmental factors (Yi and Chan 2015). Despite an increase in workplace claims, injuries, and accidents, there are few regulatory measures in place to safeguard workers against climate-related hazards (Kiefer et al., 2016). Furthermore, the regulations are more generalized and less precise to fulfill the needs of a wide range of people (Gubernot et al., 2014; Arbury et al., 2016). Therefore, the purpose of this study is to (1) Summarize the physical and mental obstacles that construction workers encounter as a result of working in extremely cold weather, (2) examine the health issues of the workforce in cold weather based on the physiological indicator heart rate, and (3) analyze the health issues faced by workers based on personal variables such as personal protective clothing comfort and workers' acclimation to cold weather conditions. In order to evaluate and assess the issues faced by construction employees in cold weather, a self-administered survey was created and distributed.

The findings of this study will help legislators and construction industry professionals set precise recommendations and regulations to safeguard workers from climate-related health hazards.

6.3. Literature Review

6.3.1. Thermoregulation in Cold Temperatures

The human body attempts to sustain internal heat by reducing heat loss to prevent the reduction in core body temperature in response to exposure to extreme cold weather (DeGroot and Kenney 2007). Cold stress is caused by a failure to maintain an optimal core body temperature in response to cold (Rodahl 2003). The human body's ideal temperature to function is around 98 degrees Fahrenheit or 37 degrees Celsius, as measured by a rectal thermometer. Any deviation from this range could cause discomfort as well as other physiological effects including cold stress in the body (Osilla et al., 2018). When the mechanism of thermoregulation fails, the core body temperature (CBT) gets reduced resulting in various changes in the body. These changes can be classified into two types: 1.Direct effects, and 2. Indirect effects. Direct effects from reduced CBT are hypothermia, shallow breathing (known as hypoventilation), critical functioning of cardiac and cerebrum, i.e., the cardiac system functions intensively in order to pump more blood as the blood vessels get narrower. Indirect effects of lowered CBT are pneumonia, frostbite, influenza, and shivering (Conlon et al., 2011; Gronlund et al., 2018).

In the initial stages of exposure to cold weather, when the body tires to sustain heat, extremities begin to cool down by allowing vasoconstriction of skin. During this process, the oxygenated blood is pumped to core organs to sustain the functionality. If there is more heat loss from the body, it means that the CBT is gradually decreasing and the body exhibits symptoms like shivering, difficulty in breathing, and rapid heart rate. It is important that the exposed person be removed from such cold temperatures immediately, otherwise, the person may further experience lowered brain function and even stroke due to cardiac failure upon extended exposure in cold weather (Analitis et al., 2008; Launay and Savourey 2009; Conlon et al., 2011; Alba et al., 2019). The series of internal reactions occurring in the body due to cold exposure is briefly summarized in the Figure 6.1. below.

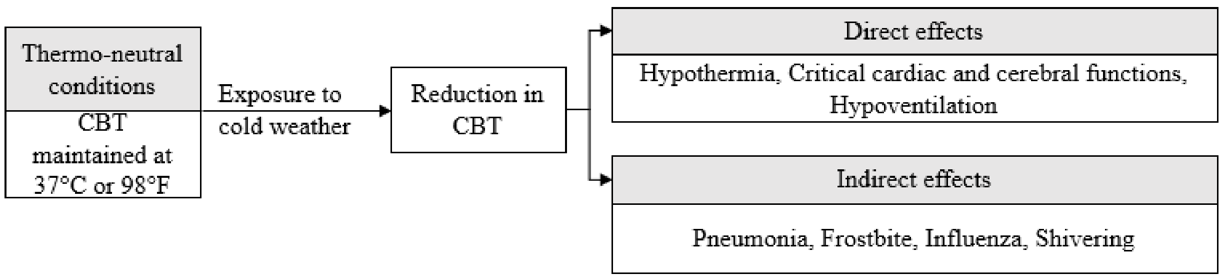


Figure 6. 1. Brief Representation of Internal Reactions and Responses in Cold Temperatures

6.3.2. Health Challenges in Cold Weather Conditions

According to international standards, workplaces with temperatures below 10 degrees to 15 degrees Celsius are considered as cold work (Ikäheimo and Hassi 2011). Workers in cold weather conditions with improper protective gear are at risk of experiencing frostbite, numbness of exposed body parts, necrosis, and trench foot or immersion foot conditions (Golant et al., 2008; Imray et al., 2011; Angelova 2017; Rakhmanov et al., 2018). Workers also experience skin problems such as dry skin, and irritation (Rodahl 2003). Working in extreme cold weather could also cause respiratory issues in upper, lower respiratory tract (Rodahl 2003; Harju et al., 2010; Hyrkäs-Palmu et al., 2018; Sugg et al., 2019), hypothermia, vasoconstriction in blood vessels (Rodahl 2003; Castellai et al., 2010; Budhathoki and Zander 2019), cardiovascular diseases like myocardial infarction, poor abdominal condition (Ikäheimo and Hassi 2009; Urban et al., 2014; Farbu et al., 2021) and range of musculoskeletal disorders from wrist pain, shoulder pain to complete body pain (Borstad et al., 2009; Burstrom et al., 2013; Farbu et al., 2019; Renberg et al., 2020). Inappropriate and tight fitting personal protective clothing could also induce hobbling effect in workers. Workers may also experience dexterity in handling tools (Cheung 2015; Ray et al., 2017). Increase in slips and fall related accidents could be observed due to slippery surfaces in workplace (Bonafede et al., 2016).

Mental challenges faced by workers when exposed to cold weather include workers becoming disoriented, aggressive, and hallucinatory (Tiwary and Gangopadhyay 2011). Reduced coordination between mental and muscular function is observed (Rodahl 2003). Workers also experienced psychological stress. Overall worker productivity is found to decrease when exposed to working in extreme cold weather conditions (Tiwary and Gangopadhyay 2011).

6.3.3. Population Vulnerable to Cold Weather Conditions

The impact of cold weather illnesses is based on socio-demographic characteristics of an individual. Certain group of individuals could be deemed to be more susceptible to effects of cold weather exposure compared to others. These characteristics need to be identified so that effective welfare policies could be introduced (Conlon et al., 2011; Haman et al., 2022). In worksites, identification of such vulnerable worker groups can be helpful to prevent workplace injuries and accidents. When exposed to cold weather, elderly individual who are above 65 years of age are known to be more vulnerable which could be possibly attributed to compromised thermoregulatory mechanism (Conlon et al., 2011; Kingma et al., 2011). However, the relationship between age and cardiovascular mortalities caused due to cold weather are found to be inconsistent as younger individuals are also susceptible to cardiovascular deaths. Based on gender, older females are susceptible to cold weather mortalities than male counterparts (Conlon et al., 2011; Zeka et al., 2014). Individuals who are located in places that are moderately cold also need to be more cautious when exposed severe cold conditions as they might not be used to such inclement weather due to lack of acclimatization (Conlon et al., 2011; Åström et al., 2019). Based on ethnicity, individual from African descent could be more vulnerable to cold related injuries compared to Caucasians (DeGroot et al., 2003; Burgess and Macfarlane 2009; Maley et al., 2014). Rising number of cold weather mortalities from countries like United States, Taiwan, Europe, Korea and Brazil emphasizes the importance of cold weather health issues and the need to develop a stringent cold weather policies for exposed population (Conlon et al., 2011).

6.3.4. Regulations and Recommendations to Protect Workers in Cold Environment

According to Occupational Safety and Health Administration (OSHA), employers need to provide training to workers in identifying and recognizing the hazards due to working in cold environment. Workers need to have awareness on the health consequences and illnesses caused upon exposure to cold weather. Workers should also be able to know the first aid measures in case if they encounter any accidents. Enlightening the workers about the effectiveness of Personal Protective Equipment (PPE), engineering controls and safe work practices can also help in reducing the risks of cold stress according to OSHA (Occupational Safety and Health Administration [OSHA], 1970). Employers should install sufficient radiant heaters and shield work areas from wind so that wind chill could be reduced. Appropriate clothing and adopting layered clothing can help in insulating sufficient heat in cold weather (OSHA 1970; Farbu et al., 2019). OSHA states that cold stress is probable to cause death of an individual or may expose the individual to severe health problems. Considering the importance of cold stress, there are also no specific standards for working in cold environment except a general clause which states that employers are responsible for providing safe workplace, hazard free, including cold stress (OSHA 1970; Brown 2019). There are legislations and regulations in global scale, for example, in Finland, standards are in place for the number of layers of cold weather clothing, and employers need to pay for the clothing, temperatures at which construction work need to be halted (Mäkinen 2006; Mäkinen 2009).

Standards on Personal Protective Clothing to protect workers in cold, and textile requirements are highlighted specifically under ‘Directive on Personal Protective Equipment’ in Europe (Mäkinen 2009). There is a pressing need to introduce stringent standards, policies, and regulations to protect workers from cold weather hazards than a generalized clause due to the rising number of cold related injuries and mortalities in workplace.

6.3.5. Cold Stress Assessment Methods

As the thermo-regulatory mechanism fails, the individual exposed to cold weather experience increased heat loss. Behavioral actions are required to balance the heat loss as environmental factors cannot be controlled. The most primary and common measure to protect workers from cold weather is their clothing. However, construction workers may not feel comfortable in wearing bulky clothing as it creates resistance during movement and may create obstacles to perform laborious activities. This also increases muscular strain and muscular load. Environmental factors like wind, ice, snow and cold air may even further aggravate the existing situation by increasing mental stress in workers and results in higher rate of accidents (Baumgartner 2008; Holmér, 2009). Therefore, it is significant to look into the available international standards and incorporate risk management programs for workers performing in cold temperatures. One of the methods of cold stress assessment follows these three steps: (1) Observation stage, (2) Specialist stage, (3) Expert stage. In observation stage, the work site is observed with a prepared checklist. The checklist may include factors such as “If the workers hands and feet are protected?”, “If the workers are in contact with any cold surfaces?”. The observed factors are then graded based on the level of risk ranging from ‘no problem’, ‘slight problem’ to ‘severe problem’. In specialist stage, when the problems in the site are very complex, an ergonomist or occupational hygienist is called in to make more reliable evaluation and assessments. These may include physiological measurements and heat balance analysis. Physiological measurements include parameters like heart rate, oxygen consumption which can be observed by adopting wearable sensors (Gatti et al., 2014; Aryal et al., 2017). Monitoring workers behaviors based on physiological parameters can behave as an early warning system. In expert stage, an expert is called in to set up a risk assessment program which also includes medical examination of workers and providing increased protective measures for workers with any pre-existing medical conditions (Holmér 2009).

6.4. Research Methodology

The research methodology is divided into four stages. A detailed literature analysis was conducted in the first phase to better understand the issues faced by construction workers working in extremely cold weather. Based on a review of the literature, a list of potential obstacles for outdoor workers were determined and divided into two broad categories: physical and mental challenges in cold weather. The highlighted issues were then used to create an online survey in phase two, which was used to validate and identify more probable challenges faced by the working population in inclement weather. Because the survey involved human individuals, the designed questionnaire was then evaluated and approved by the Institutional Review Board (IRB). The survey was pilot tested, and participants were given the link to the online survey via a web-based software called Questionpro. A total of 111 responses were received from the survey distribution, which was sent to approximately 500 people. The survey's responses were ranked on a seven-point Likert scale. In phase three, the data gathered from the survey were analyzed descriptively and quantitively. The descriptive data analysis was carried out by assessing the data based on the participants' demographic characteristics, such as age, gender, ethnicity, job experience, and the kind of construction sector. Kruskal-Wallis test was used to perform quantitative analysis in order to identify the important health challenges faced by workers in cold weather conditions.

Acclimatization, clothing comfort, and heart rate were the factors considered in performing quantitative analyses for cold weather conditions. The outcomes of the data analysis were thoroughly discussed in phase four of the study. The Figure 6.2. below represents the research methodology.

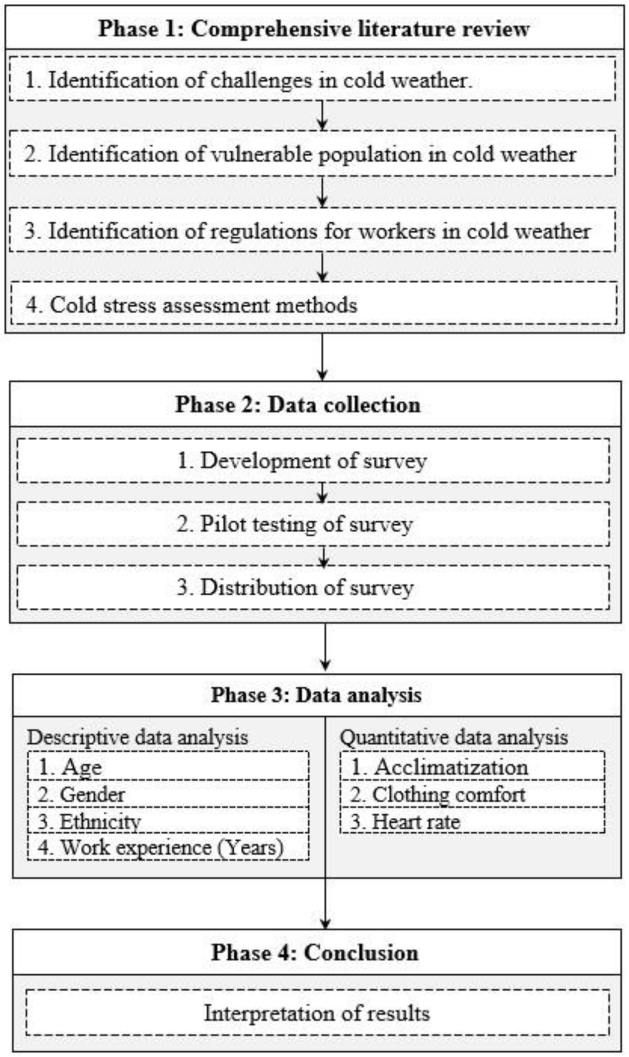


Figure 6. 2. Research Methodology

Kruskal-Wallis test: As the survey results were based on seven-point Likert scales, the Kruskal-Wallis test was used to evaluate them. The Kruskal-Wallis test is a non-parametric test that evaluates the differences between the medians of multiple groups that do not have a normal distribution. In the equation (1) below, the test statistic for the Kruskal-Wallis test is provided.

$$H = \frac{12}{n(n+1)} \sum_{i=1}^{k} \frac{r_i^2}{n_i} - 3(n+1) \quad (1)$$

In the above Kruskal-Wallis equation, (n) represents the total number of observation, (K) represents the number of groups, (r) represents the rank of each group, (n_i) represents the number of observations in group (i) (Montgomery and Runger 2003). In this study, the challenges faced by the workers were tested based on two categories, physiological indicator and personal indicator. Clothing comfort and Workers acclimatization are considered as personal parameters. Physiological indicators include workers' heart rate and blood pressure. The hypothesis used for the study is represented in Table 6.1. below.

Table 6. 1. Research Hypothesis Adopted for the Study

S.NO	Hypothesis
1.	**Null Hypothesis (H_o):** Health challenges of working in extreme cold weather conditions does not vary based on workers' acclimatization. **Alternate hypothesis (H_a):** Health challenges of working in extreme cold weather conditions varies based on workers' acclimatization.
2.	**Null Hypothesis (H_o):** Health challenges of working in extreme cold weather conditions does not vary based on workers' heart rate. **Alternate hypothesis (H_a):** Health challenges of working in extreme cold weather conditions varies based on workers' heart rate.
3.	**Null Hypothesis (Ho):** Health challenges of working in extreme cold weather conditions does not vary based on discomfort caused due to protective clothing. **Alternate hypothesis (Ha):** Health challenges of working in extreme cold weather conditions varies based on discomfort caused due to protective clothing.

6.5. Data Collection

6.5.1. Survey Development

There were about 25 questions in the developed online survey. The questionnaire was divided into several sections, including demographic questions, behavioral questions, and questions that help in recognizing physical and mental issues associated with cold weather. Workers' age, level of education, industry experience, specialization, and any pre-existing medical issues can all be identified using demographic questionnaires. Workers' drinking habits, smoking habits, and awareness of extreme weather-related concerns can all be identified using behavioral questions. The majority of the questions included seven-point Likert-scale answers, with only a handful having binary options such as Yes or No. The survey was created using Questionpro, an online tool for creating, developing, and distributing surveys. The survey participants were from private construction firms who were selected through the websites of the organizations and contacted via email. After many rounds of survey distribution and follow-up emails, a total of 111 responses were received. The survey was distributed all over United States and the responses were received from various states across the US. The survey participants were not compensated in any way for their participation. The only requirement for survey participants was that they be over the age of 18 and work in a construction-related field.

6.6. Descriptive Data Analysis

The survey's 111 responses were descriptively examined to learn more about the respondents' demographic profiles. Males comprise the majority of the participants in terms of gender. Approximately 87 percent of the participants were males, whereas only 13 percent were females. Sixty percent of the participants were over the age of fifty, twelve percent were between the ages of thirty and forty, and twenty-eight percent were between the ages of twenty-one and thirty. The ethnicity of the subjects revealed that 63 percent were Caucasians and 30 percent were Asians. About 45 percent of respondents worked in the commercial sector, 25% in infrastructure, and 9% in heavy construction and residential building, respectively. The duties of the participants range from management to specialized employment. Construction project manager, project engineer, corporate safety director, design engineer, and associate vice president were among the managerial roles held by the participants. Masonry foreman, roofing specialist, ironworker, concreting, and plumbing were some of the specialty positions occupied by the respondents. About 25% of the respondents have more than 30 years of experience in the construction sector, while 23% have less than 5 years of experience. The Figure 6.3. below represents the demographic information of the participants from the survey.

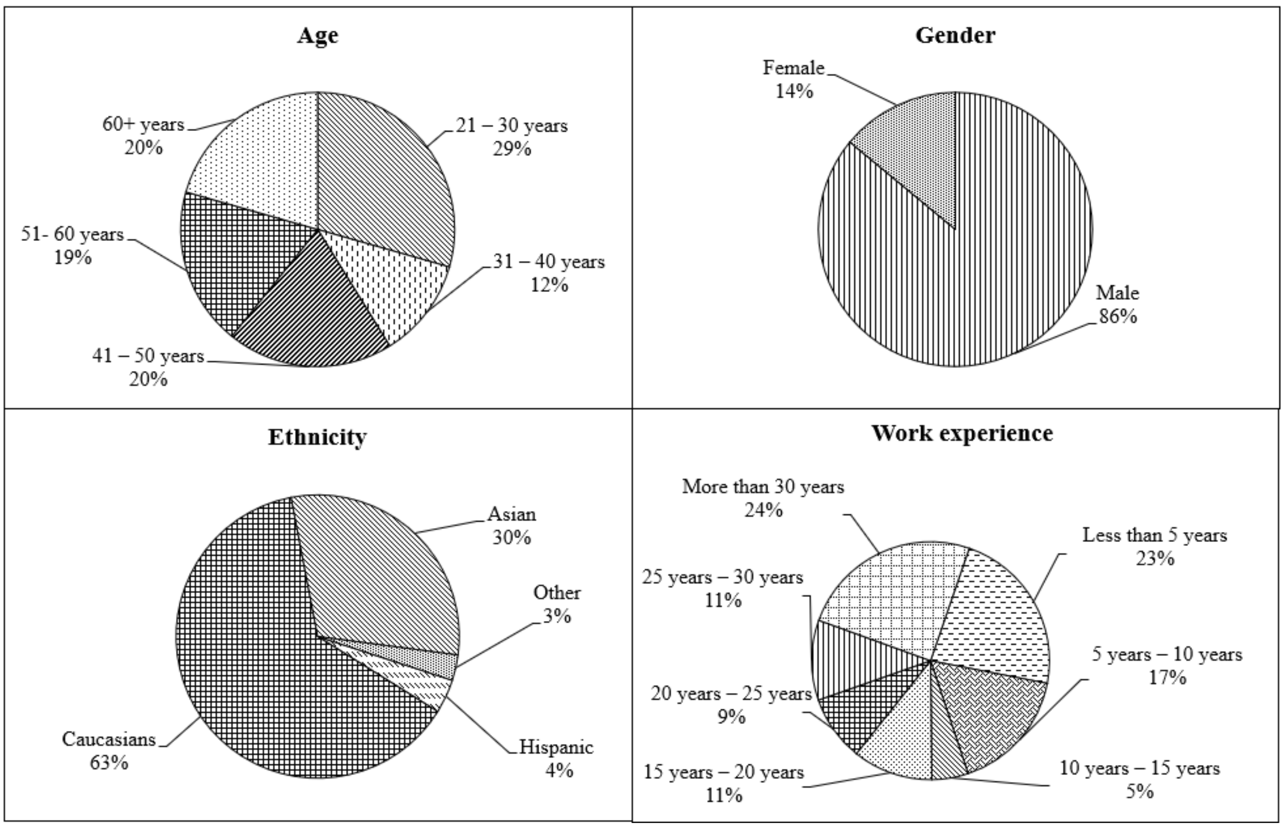


Figure 6. 3. Demographic Information of Survey Respondents

6.7. Quantitative Data Analysis

6.7.1. Results and Discussion

6.7.1.1. Identifying Significant Challenges in Cold Weather Based on Workers' Acclimatization

The responses collected from the survey were statistically analyzed using Kruskal-Wallis test as majority of the survey questions were based on seven-point Likert scales. The Kruskal-Wallis test was performed for cold weather conditions using various factors. The p-value for cold weather conditions based on workers' acclimatization characteristics for physical health challenges are represented in Table 6.2.

Table 6. 2. P-Values Testing the Significance of Physical Challenges Based on Workers' Acclimatization

Category	#	Factors/ Challenges	P-Values based on workers' acclimatization
Physical challenges in cold weather conditions (PCW)	PCW1	Inflammation	0.204
	PCW2	Frequent slips and fall	0.731
	PCW3	Hypothermia	0.003**
	PCW4	Frostbite	<0.001**
	PCW5	Trenchfoot	0.006**
	PCW6	Skin problems	0.854
	PCW7	Inability to work due to freezing body parts	0.018**
	PCW8	Respiratory issues	0.603
	PCW9	Major injuries/accidents in workplace	0.085
	PCW10	Wrist pain	<0.001**
	PCW11	Increase in muscular load	0.068
	PCW12	Poor abdominal condition	<0.001**
	PCW13	Physical fatigue	0.534

Note: ** denotes 95% level of confidence.

In cold weather conditions, six of the thirteen physical health challenges listed in Table 6.2. were significant by acclimatization. Hypothermia, frostbite, trenchfoot, inability to work due to freezing of exposed body parts, wrist pain and poor abdominal conditions were significant in cold weather conditions. Exposure to cold weather for short duration to acclimatize, delays the onset of shivering and generates more internal heat. When core body temperature falls below thermosregulatory range, mechanisms like vasoconstriction and shivering occurs further leading to hypothermia (Weant et al., 2010). As such, when workers are allowed to acclimatize, the delayed onset of shivering helps in reducing hypothermia. Workers acclimatized to cold weather are known to experience delayed onset of cold weather challenges such as freezing of body parts and frostbite due to increased metabolic heat production. This could also possibly be attributed to efficient thermal insulation on the skin and reduced vasoconstriction in acclimatized workers (Castellani and Young 2016). Wrist pain Whole body acclimatization also helps in improving localized sensitivity, i.e., in fingers and exposed extremities. Wrist pain could also be induced from the manual construction tasks. The addition of cold weather increases the intensity of wrist pain and any physical pain. An acclimatized individual might be used to such conditions compared to unacclimatized worker as evidence indicate that there is improvement in thermal discomfort (Kermanidas et al., 2022). Workers who are acclimatized are probable to experience milder conditions of trenchfoot compared to unacclimatized workers. This could possibly be due to variation in cold-indued vasodilation on acclimatized and unacclimatized workers (O'Brien and Frykman 2003).

Construction workers experience abdominal issues that might be related to gastro-intestinal issues, kidney or bladder infections (Deacon 2003). Cold temperatures intensify the risk of gastric issues (Morral-Puigmal et al., 2018) and abdominal pain due to kidney or bladder issues are due to lack of sufficient sanitary facilities in construction sites (Kulkarni 2007; Loganathan and Kalidindi 2016). There is a continuous demand for improvement in sanitary facilities all over the world and cold weather conditions makes it even more challenging (Leblanc et al., 2019). Abdominal pain in workers improved based on acclimatization, however construction sites should not only ensure acclimatization of workers, but sanitary facilities are also more important for a hygienic workplace.

Three of the five mental challenges were perceived to be significant in cold weather conditions. These include inability to concentrate, mental stress, and frequent mood fluctuation. The p-value for cold weather conditions based on workers' acclimatization characteristics for mental health challenges are represented in Table 6.3.

Table 6. 3. P-Values Testing the Significance of Mental Challenges Based on Workers' Acclimatization

Category	#	Factors/ Challenges	P-Values based on workers' acclimatization
Mental challenges in cold weather conditions (MCW)	MCW1	Inability to concentrate	0.043**
	MCW2	Manual dexterity while handling tools	0.578
	MCW3	Mental stress	0.045**
	MCW4	Frequent mood fluctuation	0.025**
	MCW5	Need for longer break duration	0.171

Note: ** denotes 95% level of confidence.

The perceptions of workers on mental health improved after being habituated to cold weather conditions. These include overcoming mental challenges such as inability to concentrate, frequent mood fluctuation, inability to control temper and inability to self-pace. Workers managed to get more control of their mental ability after acclimatization to local weather conditions. The cognitive ability of workers such as concentration improved after getting habituated to such conditions which supports the findings from previous studies (Rintamäki 2001; Mäkinen et al., 2006). Therefore, the identified significant challenges interpret that they vary based on workers acclimatization to local weather. Irrespective of workers being acclimatized or not, inflammation, and slips and fall related accidents in cold weather were found to be same across categories. Cold acclimations are well known to have significant improvement in workers' physiological challenges and their ability to tolerate cold weather conditions. Therefore, it is important that workers need to be acclimatized before exposing themselves in extreme cold weather conditions. Professionals in construction industry need to emphasize the importance of acclimatization before beginning the work.

Mandatory laws that encourage worker acclimatization need to be enforced in workplace so that workers could be protected from severe health related hazards.

6.7.1.2. Identifying Significant Challenges in Cold Weather Based on Workers' Heart Rate

Heart rate of an individual is an important physiological indicator of cold strain. The physiological responses when exposed to cold weather conditions can be indicated based on workers' heart rate. The responses from the survey were analyzed based on workers' perception of heart rate during physical exertion in extreme cold weather conditions. The significant physical challenges based on the results of P-value are represented in Table 6.4.

Table 6. 4. P-values Testing the Significance of Physical Challenges Based on Heart Rate

Category	#	Factors/ Challenges	P-Values based on heart rate
Physical challenges in cold weather conditions (PCW)	PCW1	Inflammation	0.001**
	PCW2	Frequent slips and fall	0.247
	PCW3	Hypothermia	0.038**
	PCW4	Frostbite	0.019**
	PCW5	Trenchfoot	0.075
	PCW6	Skin problems	0.053
	PCW7	Inability to work due to freezing body parts	0.027**
	PCW8	Respiratory issues	<0.001**
	PCW9	Major injuries/accidents in workplace	<0.001**
	PCW10	Wrist pain	0.001**
	PCW11	Increase in muscular load	<0.001**
	PCW12	Poor abdominal condition	<0.001**
	PCW13	Physical fatigue	0.003**

Note: ** denotes 95% level of confidence.

In cold weather conditions, ten of the thirteen physical challenges were found to vary among worker groups based on heart rate. Inflammation, hypothermia, frostbite, inability to work due to freezing of exposed body parts, respiratory issues, major accidents, wrist pain, increase in muscular load, poor abdominal condition and physical fatigue were the significant physical challenges in cold conditions. Heart rate increases when the body is in rewarming phase. Workers are likely to exhibit varied heart rates when they are experiencing hypothermia and freezing of body parts due to shivering. Features like higher heart rates are observed in individuals severely injured for frostbite conditions (Schellenberg et al., 2020). Lowering of body temperature below standard core body temperature referred to as hypothermia also revealed reduced heart tones (Pozos and Danzl 2001). Struggled breathing like shortness of breath accompanied by variation in heart rate is also observed during respiratory issues among workers during cold weather. Workers perception on physical fatigue and increase in muscular load were also influenced by difference in heart rate due to intense demanding operations in cold weather. Muscle damage in cold weather is attributed to reduced blood flow in cold conditions (Gregson et al., 2011). As the thermo-regulatory mechanism increases to prevent heat escaping from the body, heart rate could possibly act as an indicator of workers experiencing such challenges. Workers experiencing injuries and accidents are likely to exhibit varied heart range than workers who are working with increased safety. Adopting wearable technologies with heart rate sensors can be helpful in identifying workers unsafe behavior (Kazar 2020). Four of the five mental challenges were significant in cold weather conditions. These include inability to concentrate, dexterity, mental stress and frequent mood fluctuation. The significant mental challenges based on the results of P-value are represented in Table 6.5.

Table 6. 5. P-Values Testing the Significance of Mental Challenges Based on Heart Rate

Category	#	Factors/ Challenges	P-Values based on heart rate
Mental challenges in cold weather conditions (MCW)	MCW1	Inability to concentrate	<0.001**
	MCW2	Manual dexterity while handling tools	0.006**
	MCW3	Mental stress	<0.001**
	MCW4	Frequent mood fluctuation	0.008**
	MCW5	Need for longer break duration	0.510

Note: ** denotes 95% level of confidence.

Increasing heart rate in cold weather keeps the worker distracted as the body is internally fighting to thermoregulate resulting in dexterity, reduced concentration levels in workers. Increase or decrease in heart rate when workers are performing in unfavorable cold weather conditions often result in compromised mental state leading to mental stress, inability to concentrate, frequent mood change and need for longer breaks. The identified significant challenges interpret that the challenges vary based on workers' heart rate as heart rate is an important indicator in individuals experiencing cold strain (Ohashi et al., 2018; Yao et al., 2018). However, challenges such as trenchfoot and skin problems are not indicated by heart rate, and it is similar across categories. Rapid increase or decrease in heart could be related to workers experiencing cold stress as the physiology of the body tries to thermoregulate resulting in further health consequences like hypothermia, when the effects of cold are further ignored. Several technologies with embedded heart rate sensors can be used as a monitoring system in employees exposed to extreme weather conditions. This can aid in protecting the workers by indicating early signs of health hazards when exposed to unfavorable weather conditions.

6.7.1.3. Identifying Significant Challenges in Cold Weather Based on Workers' Clothing

Personal protective clothing (PPC) plays an important role in entrapping the heat while working in cold weather conditions. PPC with right fit is important when working in cold weather conditions. A loose fit PPC cannot entrap required amount of heat whereas a tight fit PPC can cause hobbling effect and discomfort in workers. A PPC with improper fit is one of the primary causes of exposing body parts in cold weather leading to chain of challenges, when working in cold weather. The significant physical challenges identified based on workers' clothing comfort in cold weather is presented in Table 6.6.

Table 6. 6. P-values Testing the Significance of Physical Challenges Based on Clothing

Category	#	Factors/ Challenges	P-Values based on clothing
Physical challenges in cold weather	PCW1	Inflammation	0.820
	PCW2	Frequent slips and fall	0.023**
	PCW3	Hypothermia	0.007**

conditions (PCW)	PCW4	Frostbite	0.266
	PCW5	Trenchfoot	0.161
	PCW6	Skin problems	0.008**
	PCW7	Inability to work due to freezing body parts	0.006**
	PCW8	Respiratory issues	0.005**
	PCW9	Major injuries/accidents in workplace	0.083
	PCW10	Wrist pain	0.026**
	PCW11	Increase in muscular load	0.002**
	PCW12	Poor abdominal condition	0.284
	PCW13	Physical fatigue	0.003**

Note: ** denotes 95% level of confidence.

Thermal insulation due to clothing is a significant factor while performing in cold weather conditions. The P-values from Kruskal-Wallis test indicates that eight of the thirteen physical challenges were significant among workers wearing uncomfortable personal protective clothing and workers using comfortable protective clothing. The identified significant challenges in cold weather include frequent slips and fall accidents, hypothermia, skin problems, inability to work due to freezing of body parts, respiratory issues, wrist pain, increase in muscular load, and physical fatigue. PPC with improper fit can cause hobbling effect in workers leading to slips and falls, exposes body parts resulting in freezing of tissues which further leads to physical fatigue. Improperly fit PPC can cause workers to hobble, and increases fall related accidents. Inadequate clothing cannot sustain sufficient heat and thus results in early onset of hypothermia (CDC 2005). Construction workers need to perform more manual work which causes wrist pain by itself, and the intensity of wrist pain increases with unfavorable cold weather and improper protective gear. Four of the five mental health challenges were found to be significant in cold weather. These challenges include inability to concentrate, mental stress, dexterity and need for longer duration of breaks. The significant mental challenges identified based on workers' clothing comfort in cold weather is presented in Table 6.7.

Table 6. 7. P-values Testing the Significance of Mental Challenges Based on Clothing

Category	#	Factors/ Challenges	P-Values based on clothing
Mental challenges in cold weather conditions (MCW)	MCW1	Inability to concentrate	0.014**
	MCW2	Manual dexterity while handling tools	0.001**
	MCW3	Mental stress	0.006**
	MCW4	Frequent mood fluctuation	0.237
	MCW5	Need for longer break duration	0.038**

Note: ** denotes 95% level of confidence.

Lack of sufficient insulated clothing adds mental stress to workers as the body thermos-physiologically tries to cope with reduced temperatures, causing the workers to distract away from the work. Extremities of the body gets cooled quicker than any other body parts. As construction workers need to perform more manual tasks, drop in finger temperature causes loss in sensitivity and thus workers experience manual dexterity (Jussila 2016). Clothing materials of gloves play an important role in protecting finger temperatures and thus workers perception on manual dexterity based on protective clothing is significant. Increase in metabolic energy due to inappropriate clothing fit and compromised quality of the clothing yields inefficient heat conservation as more heat is lost. As such workers possibly experience increased physical fatigue resulting in need for longer break hours. Therefore, the perception of workers to require longer break hours varied based on their clothing comfort. However, challenges such as inflammation and poor abdominal conditions are not caused due uncomfortable PPC, and they are experienced similarly throughout the workers. Inappropriate clothing hinders movement in workers.

6.8. Conclusion

Construction workers are most affected by temperatures extremes in cold weather conditions. It is important for employers in construction sites to ensure the safety of their employees from cold weather-related health hazards. This paper sought to identify the challenges faced by construction workers in cold weather conditions and categorized them as physical and mental health challenges. The 111 responses received from questionnaire survey were gathered and statistically analyzed based on workers' acclimatization, heart rate, and personal protective clothing. Well acclimatized worker and PPC of right fit are two important personal factors that improves the challenges of working in cold weather conditions. Challenges such as hypothermia, frostbite, freezing of body parts, trenchfoot conditions are perceived differently in acclimatized workers than unacclimatized workers. Acclimatized workers' perception on mental health challenges such as inability to concentrate and frequent mood fluctuation were likely to be different than unacclimatized workers. Workers' perception on challenges such as slips and falls, freezing body parts, physical fatigue are likely to be experienced differently in workers with a comfortable personal protective clothing. Mental challenges like inability to concentrate, need for longer breaks, and metal stress were perceived differently in workers with comfortable protective clothing. Monitoring workers' heart rate when working in cold weather conditions helps in identifying workers who are experiencing cold stress. Workers perception on challenges such as inflammation, frostbite, hypothermia, freezing of body parts, increase in muscular load, physical fatigue, dexterity can be identified based on varying heart rate.

Due to limited studies focusing on health issues experienced by workers in construction sector in cold weather, this study contributes to the existing body of knowledge by analyzing the health challenges experienced by construction workers when performing in cold weather conditions based on various physical and personal indicators. More clinical evidence on the results of this study will be more supportive than just empirical results which is considered as the limitation for this study. A complete explanation based on clinical evidence will contribute to a precise understanding of workers health challenges in cold weather conditions. Monitoring workers heart rate to identify workers undergoing cold stress, ensuring if workers are acclimatized before exposing to severe cold conditions and providing PPC with right fit are significant in improving challenges and their working conditions in cold weather. The results of this study can be used by professionals in construction industry to identify challenges and take preventive measures to protect workers from cold weather-related hazards.

CHAPTER 7

A STUDY ON OCCUPATIONAL HEALTH AND SAFETY OF CONSTRUCTION WORKFORCE IN HOT TEMPERATURES

7.1. Abstract

Climate change is one of the factor for increase in the number of days with heat waves. Health consequences of hot weather days can be observed in individuals who are actively engaged in outdoor activities. Construction sector is one of the industries that requires active involvement of laborers carrying out physically demanding activities in extreme heat. Exposing the workers to unfavorable weather conditions results in various health problems and poses safety risks. These weather-related health challenges impact individuals in different ways based on their demographic characteristics. Therefore, the purpose of this study is to identify the demographic predictors causing heat related health problems and safety issues in construction workers when performing in extreme conditions. A survey was conducted after a thorough literature review which helped in identifying the various physical health challenges experienced by the workers when performing physically demanding activities in unfavorable weather conditions. The results obtained from the survey were then analyzed using logistic regression technique to determine the odds of heat related health problems reported by the individuals. The results revealed that the effects of temperature on the exposed population is not uniform and varies based on demographic attributes such as age, gender, ethnicity and type of construction sector. Male workers were found to be more affected in terms of respiratory health than female workers. The results also suggested evidence on the relationship between physical exhaustion, their working environment and their ethnicity in hot weather conditions. Also, the number of accidents increased when performing in extreme hot weather conditions. The findings of this study will assist professionals and legal bodies in developing tailored strategies for workers at risk.

Keywords: Construction, Extreme Heat, Weather, Health, Workplace Safety

7.2. Introduction

Extreme weather events have been increasing in recent years. These may vary from severe disasters to extreme hot and cold weather days. Climate change has been linked to such extreme conditions (Meehl and Tebaldi 2004). Heat waves are one of the results of climate change affecting more individuals every year (Luber and McGeehin 2008). Some of the observable impacts caused by the increase in hot weather days are the rising number of heat related morbidities and mortalities during summer months (Kovats and Hajat 2008). There has been a rise in the number of heat related deaths on a global scale over recent years. In the year of 2003, 70,000 mortalities have been recorded in Western Europe (Robine et al., 2003). In France, 14,800 and more deaths were recorded due to heat (Dhainaut et al., 2004; Priard et al., 2005). In United-States, extreme hot weather is considered as one of the major causes of weather-related mortalities, where almost 688 deaths were reported to be of completely associated to heat every year (Akompab et al., 2013). A very high number of heat related mortality were reported by Russia in the year 2010. Australia is also one of the countries impacted by extreme heat and is known to have more heat related deaths than deaths caused by natural disasters. Every year, over thousands of deaths were accountable to heat waves alone (Reeves et al., 2010; Dole et al., 2011; Akompab et al., 2013). The estimates reported every year indicates that there is a worldwide risk for heat related morbidities and mortalities.

Construction industry employs a great number of workforce with the rising number of construction projects. Construction sector is also regarded as one of the riskiest industries due to safety hazards and rising number of accidents (Kermanshachi et al., 2019; Kermanshachi et al., 2020a; Safapour et al., 2020). The nature of the work in construction is more dynamic requiring workers to perform in unfavorable working environment (Kermanshachi et al., 2018). This not only involves performing in unfavorable temperatures but are also accompanied with pollution (i.e, dust) and condensation in worksites. Working conditions include prolonged standing, performing laborious activities such as carrying heavy load, operating in a noisy environment, handling tools with vibration and even exposed to harmful chemicals. Workers might also have to perform in heights. Some of such activities include scaffolding and roofing operations. These workplace conditions are known to create additional risks in terms of safety while workers are performing in extreme unfavorable weather conditions. These unsafe conditions can be prevented if appropriate safety measures are adopted (Umar and Egbu 2018; Kermanshachi and Rouhanizadeh 2019).

The National Institute of Occupational Safety and Health (NIOSH) stated that majority of the heat related mortalities have been from construction industry. Factors such as working with machinery, working at elevations, handling heavier workload, along with direct exposure to sunlight were identified as the risk factors for such mortalities. These accidents and mortalities could be reduced when the workers are continuously monitored. Continuous monitoring could also be carried out remotely through various advanced technologies thereby improving workplace safety (Safapour et al., 2019b; Kakamu et al., 2021; Subramanya and Kermanshachi 2022a; Subramanya et al., 2022b).

Individuals exposed to extreme heat are impacted in different ways and varies based on various social factors. Elderly individuals and those with chronic illnesses are more vulnerable to heat related health effects than others (Åström et al., 2015). Any pre-existing health conditions such as cardiovascular health problems, pulmonary issues and even psychiatric conditions were known to be strongly linked with heat related mortalities (Bouchama er al., 2007; Elisabeth et al., 2018; Subramanya and Kermanshachi 2021). Morbidities and mortalities caused due to hot weather conditions have now become a public concern due to the frequency of its occurrence. This creates the need for introducing efficient preventive measures, awareness programs and increased interventions on a global scale (Kovats and Kristie 2008; Kovats and Hajat 2008; Karthick et al., 2022c). Identifying social factors that makes the individual's health more vulnerable upon exposure to heat are very important for developing protective measures.

Construction workers performing intense physical activities in extreme hot weather become easily drained due to the scorching heat and the working conditions. Their mental ability decreases resulting in reduced productivity, impaired reasoning ability, reduction in the response rate and reduced mental alertness. Due to this reason, the workers are more likely to be involved in fatal accidents (Melagoda and Rowlinson 2021).

Events caused due to climate change, and demographic trends indicates that extreme heat could continue to be a major hazard in coming years, affecting wide range of population and individuals at-risk. Therefore, there is a need to understand which population is more susceptible to the effects of heat (Zahoor et al., 2016; Hayden et al., 2017; Acharya et al., 2018; Karthick et al., 2022g), so that effective interventions could be introduced (Kermanshachi and Safapour 2019; Kermanshachi et al., 2021a; Kermanshachi et al., 2021b; Safapour et al., 2021). The Occupational Safety and Health Administration (OSHA) has made various recommendations for workers performing in hot weather conditions, although there are comparatively less enforcements at a federal level. The existing guidelines are also quite generic and need to be more specific to prevent workplace heat related illnesses in construction sites. Employers are held responsible to protect workers from any workplace hazards including extreme hot weather conditions. Therefore, the aim of this study is to identify the various challenges experienced by workers in construction industry and develop a model using logistic regression technique for workers' injuries, physical fatigue and respiratory issues that are observed during hot weather conditions, based on various demographic attributes. The results identified in this study will help professionals in construction industry to identify which workers are more vulnerable when working in hot weather, thereby can support them in planning preventive measures and interventions, improving the safety of the workplace.

7.3. Literature Review

Human mortalities due to weather related outcomes are increasing every year and extreme heat is regarded as one of the leading causes in United States and on a global scale (Hajat and Kosatsky 2010). When the daily temperature rises above the normal range, various negative health consequences begin to surface. The magnitude of these health consequences depends on the intensity of exposure and various other social factors (Hayden et al., 2017; Karthick et al., 2022e). Construction industry is regarded as one of the industries with higher risk for safety due to the significant number of injuries and accidents occurring every year and heat is one of the contributing factor that requires attention (Safapour et al., 2019c; Melagoda and Rowlinson 2021; Kermanshachi and Pamidimukkala 2022; Kermanshachi et al., 2022b; Namian et al., 2022). The various health outcomes caused due to exposure to heat and how hot weather conditions affects the workplace and construction industry are elaborated in the following sections.

7.3.1. Heat Stress in Outdoor Working Population

The physiology of humans tries maintaining the core body temperature within a certain range according to their external environment. This mechanism occurs effectively when the body can dissipate the excess heat. Approximately, 37-degree Celsius (or 98-degree Fahrenheit) is considered as an optimal range for a human body to function. However, when the excess heat is not dissipated, the core body temperature increases, resulting in heat stress (Cramer and Jay 2016). As the core body temperature increases, the body also exhibits negative health outcomes. These changes in the core body temperature imposes various health and safety challenges in occupational settings (McGregor and Vanos 2018). Heat stress in occupational settings leads to various workplace injuries, deaths, reduction in productivity of workers due to impaired physiological reactions. Workers in construction industry are known to be the most affected in terms of heat stress compared to workers in other occupational settings (Yi and Chan 2017; Umar and Egbu 2018).

7.3.2. Health Challenges of Exposure to Hot Weather Conditions

According to International Labor Organization, almost 1 billion workers and more are affected in heat related health issues. These estimates are known to increase in coming years (Kjellstrom et al., 2019). Workers performing in an outdoor occupation generate internal metabolic heat in addition to the heat from external environment. Therefore, the combination of metabolic heat production, heat from the external environment, and conditions such as humidity leads to heat strain in the individual. Metabolically produced heat that occurs when an individual is physically exerting, may increase further when performing in hot weather conditions (Poulianiti et al., 2018; Ebi et al., 2021).

The inability to regulate internal body temperature results in various health effects that are manifested as physical symptoms and mental symptoms (Aghamohammadi et al., 2021). The rising of core body temperature is linked with increasing heat rate and rate of breathing (Seltenrich 2015). When exposed to prolonged duration in hot weather, there could be damages to kidneys, brain, liver, heart and lungs. Physiological impacts of heat stress include heat stroke, heat syncope, heat cramps, heat exhaustion, fatigue, and heat edema. The various physical health challenges begin to surface when the core body temperature exceeds 37-degree Celsius. Beyond this core body temperature, the blood flow in the skin also increases, also triggering the sweating mechanism (Lundgren et al., 2013). The stored heat in the body dissipates to the external environment through sweating mechanism. However, when the humidity in the external environment is very high, there is reduction in the evaporation of sweat which then contributes to increased core body temperature (Parsons 2007; Kjellstrom et al., 2016). Workers performing in extreme heat are hypo-hydrated, especially during midday and in the afternoon as the intensity of heat exposure is usually high. Inadequate dehydration practices result in chronic kidney diseases (Morioka et al., 2006). When the core body temperature rises above 38-degree or 39-degree Celsius, the exposed individual is at the risk of developing heat exhaustion and further exposure leads to heat stroke (Jay and Kenny 2010; Lundgren et al., 2013). Teratogenic effects also occur due to exposure to extreme heat (Acharya et al., 2018).

Respiratory health is considered to be more impacted followed by cardiovascular mortalities due to heat (Schwartz et al., 2004). Respiratory illnesses are considered as the secondary causes of mortalities in heatwaves (Bunker et al., 2016; Ebi et al., 2021; Karthick et al., 2022b). Association between respiratory health and morbidities have been identified by several studies (Ye et al., 2012; Wang et al., 2012; Harduar Morano 2016). Some of the illnesses related to respiratory health in hot weather conditions are respiratory alkalosis which occurs when an individual is hyperventilating, respiratory distress (Bouchama et al., 2002; Noakes et al., 2008) and chronic bronchitis (Lin et al., 2009; Green et al., 2010; Basu et al., 2012; Harduar Morano 2016). Several hospitalizations for conditions like asthma due to hot weather conditions are observed. In densely populated areas, the risk for air pollution is quite high, along with the presence of hot weather conditions increases the respiratory health problems (Michelozzi et al., 2009; Beyers et al., 2015). When external temperature is high, there is an increased chance for the air pollutants to be absorbed by the skin due to increased skin permeability (Grigorieva and Lukyanets 2021). Therefore, presence of any contaminants in the air can increase the respiratory issues.

7.3.3. Effects of Hot Weather Conditions on Workplace Safety

Workplace safety is of utmost priority in any occupational setting. However, extreme heat compromises the workplace safety by increasing injuries and accidents. The association between temperature extremes, human health and cognition is known to have impact on the safety behavior of workers in extreme conditions (Heal and Park 2016). The increase in the core body temperature affects the central-nervous systems and the cognitive ability in the exposed individual (Jackson and Rosenberg 2010). According to Bureau of Labor Statistics, 37 fatal deaths and 2830 non-fatalities in workplace due to hot weather conditions were reported in the year 2015 (Page and Sheppard 2019).

Exposure to extreme temperatures causes mental health problems that may range from minor to major illnesses. As workers continue to perform in extreme temperatures they may experience concentration issues, confusion, dexterity, and confusion which contributes to increase in the workplace accidents (Jackson and Rosenberg 2010). Workers may lack coordination, reduced response or reaction times, and decreased mental performance are observed when exposed to extreme temperatures (Seppanen et al., 2006; Page and Sheppard 2019; Pamidimukkala et al., 2022e). Considering the above-mentioned relationships, it has been stated that there is a U-shaped graphical curve with respect to temperature and risk of accidents. This implies that, as the temperature increases in both extremes (hot and cold), there is increase in accidents as well (Behrer and Park 2017; Page and Sheppard 2019). Certain construction activities are performed at higher altitudes with elevations. Such activities require physical and mental adjustments to perform at heights. These activities induce physical fatigue and when coupled with performing in extreme heat increases the risk of accidents. Workers performing at heights are more adversely affected compared to others (Wong et al., 2014).

Extreme temperatures are known to impact workers productivity to a greater extent. Productivity losses further contribute to economic loss (Stern 2013). Compromised workplace safety and exposure to extreme temperatures, therefore, also increases costs resulting in economic burden. Increase in number of workplace accidents is also due to worker fatigue which is usually higher when workers are performing in hot weather conditions (Morabito et al., 2006). Physical fatigue is an outcome of heat stress and performing physically laborious activities in unfavorable temperatures. This causes workers to take additional breaks and pacing down to prevent exhaustion (Miller et al., 2011; Zander et al., 2015). One of the studies on productivity losses in terms of cost reported that $771 million to $3.4 billion economic losses were reported in a year in Germany. Workplace absenteeism also increases when workplace safety due to hot weather is ignored (Zander et al., 2015; Safapour et al., 2022a).

7.3.4. Socio-Demographic Factors Associated with Heat Health Outcomes

The ability to tolerate heat stress varies from individual to individual. This variation is known to be impacted based on social determinants and individuals' personal characteristics (Lundgren et al., 2013). Some of these factors include age, gender, ethnicity, acclimatization and any pre-existing illnesses. Individuals who are not used to conditions of local weather could be more vulnerable to health impacts of heat compared to others (Wong et al., 2014; Pamidimukkala and Kermanshachi 2021; Pamidimukkala and Kermanshachi 2022a). Older workers, especially workers who are above 55 years are relatively more susceptible than other age groups. Female individuals and pregnant women are more susceptible to heat related health problems than male workers (Tapia et al., 2020). Individuals of Hispanic origin were known to experience more heat related health problems compared to other ethnicities (Rahman et al., 2016; Acharya et al., 2018). Certain work activities that expose individuals under direct sun can create more health problems. These activities include operations like roofing, scaffolding, concreting, bar bending and steel fixing. Workers involved in those activities should be aware of the health implications and should stay informed as they are more susceptible due to performing in top floors of the building under direct exposure to the sun (Fredericks Tycho et al., 2005; Wong et al., 2014). Individual's personal habits that involve frequent smoking and alcohol consumption could make them more vulnerable to heat related health outcomes (Acharya et al., 2018).

7.3.5. Regulations for Outdoor Workers Performing in Hot Weather

According to Occupational Safety and Health Administration (OSHA), a general clause is used to protect workers from heat related hazard, where employers are responsible to provide a safe workplace including for hazards related to heat related weather conditions. In United States, regulations at federal lever are not strictly enforced for workers performing in hot weather conditions. However, OSHA encourages workers to engage in frequent hydration practices and take more breaks when performing in hot weather conditions. Employers are suggested to ensure acclimatization practices. However, in a study conducted to investigate the heat related deaths, it has been found that, lack of acclimatization practices has led to fatalities in workplace (Arbury et al., 2016). Several other countries that experience similar weather conditions, like United Arab Emirates (UAE) and Gulf countries have enforced strict nationwide work ban in peak summer months to reduce fatalities (Joubert et al., 2011; Shah et al., 2019; Leonidas et al., 2022).

The exposure limits specified by National Institute for Occupational Safety and Health (NIOSH) in accordance with American Conference of Governmental Industrial Hygienists (ACGIH) were found to be higher when analyzing the outdoor occupational heat fatalities. In a study conducted to evaluate these exposure limits, it has been found that the exposure limits should have been lower and should also have included workers who are not acclimatized. Existing guidance for exposure limits may not be sufficient and employers follow publicly broadcasted weather reports, but they also need to consider their workplace conditions (Tustin et al., 2018).

7.4. Research Methodology

The research methodology adopted in this study follows a seven-step process. In the first step, a comprehensive literature review was performed, which involved identifying several relevant articles and studies focusing on similar area of concern. Search engines and databases such as American Society of Civil Engineers (ASCE), Springer, PubMed, Elsevier were used to identify existing studies. Some of the keywords used for the search includes “hot weather”, “morbidities” “mortalities”, “outdoor workers”, “construction sector”, “vulnerabilities”, and “existing regulations”, In the second step, the studies were used to identify the list of potential health challenges experienced by outdoor workers in hot environments. This comprehensive list of identified challenges were then used to develop an online questionnaire survey, which is the third step. The questionnaire survey was developed using an online tool known as “Questionpro”. In the fourth step, the developed survey was distributed through emails to workers in construction industry. In the fifth step, the data collected from the survey was used to perform qualitative data analysis. In the next step, the gathered data was visualized by performing univariate analysis. In the next step, the data was used to develop a predictive model with various demographic predictors in the model by adopting a stepwise approach. The figure 7.1. below represents the research methodology adopted for this study.

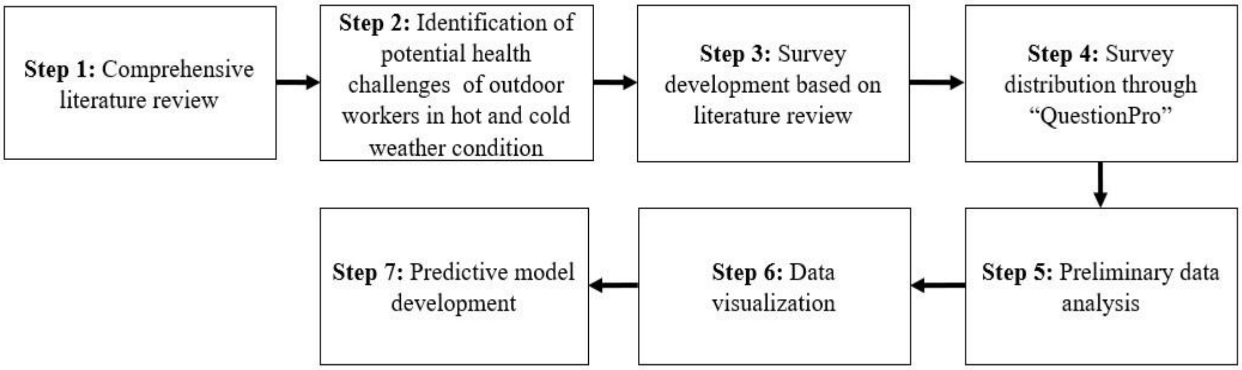


Figure 7. 1. Research Methodology

7.5. Data Collection

7.5.1. Survey Development and Distribution

A comprehensive survey was developed based on literature review to understand the challenges experienced by workers in construction industry when performing in hot temperatures. The survey comprised of 25 questions in total classified into several sections. The first section of the survey was designed to collect the demographic information of the respondents. The second section of the survey deals with questions that helps in understanding the experiences of the workers' physical health challenges in hot weather conditions. In the third section of the survey, questions were designed to understand the respondents' mental health challenges experienced due to performing in hot weather conditions. In the fourth section of the survey, questions were asked to identify behavioral attributes such as drinking and smoking habits of the respondents. The responses of the survey were recorded on a seven-point Likert scale format. The survey was distributed online by sharing the link of the survey through email. The participants for the survey were randomly selected and the only inclusion criteria set to participate in the survey was that the respondent has to an individual working in a construction sector and should be more than 18 years of age. The survey distribution yielded about 100 responses with a response rate of 41%. Some of the sample questions asked in the survey is presented in the figure 7.2. below.

Demographic questions

- Are you used to workplace temperature and humidity conditions?
- Please specify your responsibility in construction?
- Please specify the type of work environment?

Workforce hot weather challenges

- How frequently have you experienced injuries when working in hot weather conditions?
- How frequently does wearing a personal protective clothing create discomfort when working in hot weather conditions?
- How frequently have you ever felt inability to concentrate when working in extreme hot weather conditions?

Figure 7. 2. Sample Questions from the Survey

7.6. Demographic Data Analysis

The data gathered from the survey was descriptively analyzed to understand the distribution of demographic characteristics of the respondents. The total number of survey responses collected were 100 responses. The descriptive analysis revealed that majority of the responses were from males compared to females. Almost 87% of the responses were from males. Based on ethnicity majority of the responses were from Caucasians. Almost 63% of the respondents were Caucasians and 30% of the survey was undertaken by Asians. Based om work environment, 16% of the respondents were taking part in outdoor activities only and 65% of the respondents were involved in both outdoor and indoor work activities, whereas 19% of the respondents performed only indoor activities. Based on age, majority of the respondents were elderly. About 60% of the respondents were above 40 years of age and 28% of the survey respondents belonged to 21 to 30 years of age. The descriptive data analysis of the survey is presented in the table 7.1. below.

Table 7. 1. Demographic Characteristics of Survey Respondents

Characteristics of Participants	Percentage
Gender	Male – 87% Female – 13%
Ethnicity	Caucasians – 63% Asians – 30% Other – 7%
Work environment	Indoor – 19% Only outdoor – 16% Combination of both – 65%
Age	Over 40 years – 60% Between 31 – 40 years – 12% Between 21 – 30 years – 28%

7.7. Model Development

The data collected from the survey was imported into the statistical software for further analysis. The software used for analysis was "IBM SPSS Statistics" version 28.0. The data from the survey was visualized and cleaned before importing. As the responses from the survey was collected based on a Likert scale format, logistic regression modelling was used to develop a predictive model. When the outcome variable is categorical and is used to determine its occurrence, logistic regression could be a preferable option. In order to determine the occurrence of a particular health issue, epidemiological studies have widely adopted logistic regression modelling techniques (Wong 2004). Various studies focusing on the similar area of interest, which is to examine to health outcomes of populations working in extreme temperatures, used logistic regression modelling techniques (Nitschke et al., 2013; Khare et al., 2015; Lohrey et al., 2021; Dao et al., 2022). This study developed three models based on logistic regression in a stepwise approach, (1) to predict the occurrence of injuries and accidents in construction sites, (2) to predict physical fatigue experience by workers in hot weather, (3) to predict the respiratory health issues when performing in hot weather based on various socio-demographic attributes. The equation (1) below represents the simple form of a logistic equation.

$$\ln\left(\frac{\Pi}{1-\Pi}\right) = \alpha + \beta X \quad (1)$$

The term "log odds" (sometimes referred to as "logit") refers to the variable in the equation (1) which is on the left-hand side. The probability of the outcome of interest is denoted by Π in the equation. The Y-intercept in the above equation is denoted by α, and β in the equation refers to the slope. X in the equation represents the categorical variable (Abdulqader 2017).

7.7.1. Assumptions for Logistic Regression Model

The following assumptions were considered for the logistic regression model: (1) The dependent variable is assessed on a categorical scale and not on a continuous scale in the model. (2) The observed variables are independent, and the dataset is not linear. (3) More than one independent variable is present in the model and measured on a categorical scale (Field 2009; Abdulqader 2017).

7.8. Results and Discussion

7.8.1. Statistical Analysis and Results

7.8.1.1. Dependent Variable

The results of the survey were used to develop three logistic regression models. The dependent variable for the fatigue model was based on the question: how frequently have you experienced physical fatigue while working in hot weather conditions?. The dependent variable for minor injuries and accidents model was based on the question: how frequently have you experienced any minor physical injuries when performing in hot weather conditions?. The dependent variable for the model based on respiratory issues was: how frequently do you experience respiratory related issues like asthma when working in a hot weather environment?.

7.8.1.2. Independent Variable

The independent variables chosen for the model are all socio-demographic variables, as the model is intended to investigate if there is a relationship between the various demographic characteristics of the workers' and the various health challenges experienced by them in hot weather conditions. The independent variables in the model were age, gender (male, female), ethnicity (Hispanics, Caucasian, African American, Asian), type of sector (residential sector, commercial sector, infrastructure sector) and work environment.

7.8.2. Model Output

The data collected from the survey were organized and coded into SPSS for analyses. The dependent and independent variables of the model were defined to perform logistic regression. Variables that consisted of more than two categories were dummy coded and a stepwise method was adopted to enter variables in the model to ensure the best fit for the model. The table 7.2. below represents the model output from SPSS.

Table 7. 2. Model output

#	Predictors	Dependent variable					
		Physical fatigue Model 1		**Minor injuries Model 2**		**Respiratory health Model 3**	
		Sig	**Exp (B)**	**Sig**	**Exp (B)**	**Sig**	**Exp (B)**
1.	Age	0.244	0.770	0.165	0.728	0.244	1.360
2.	Gender	0.571	1.620	0.992	1.007	0.014**	1.729
3.	Ethnicity=Hispanic	0.234	1.705	0.541	0.440	0.269	0.604
4.	Ethnicity=Caucasian	0.020**	1.390	0.312	2.100	0.244	1.360
5.	Ethnicity=African American	0.732	0.392	0.850	0.210	0.137	0.268
6.	Ethnicity=Asian	0.021**	0.268	0.790	0.710	0.750	0.101
7.	Type of sector=Residential	0.387	0.396	0.497	0.488	0.009**	1.216
8.	Type of sector=Commercial	0588	0.700	0.035**	1.253	0.334	0.935
9.	Type of sector=Infrastructure	0.596	0.280	0.073*	1.224	0.820	0.113

10.	Work environment=Outdoor	0.049**	1.758	0.194	0.389	0.090*	1.851
11.	Work environment=Indoor	0.089*	0.300	0.039**	1.250	0.603	0.270

Note: ** denotes 95% level of confidence; * denotes 90% level of confidence

7.8.3. Model Interpretation and Discussion of Results

The physical fatigue, respiratory health issues and mild injuries that happen on construction sites when employees are exposed to excessive heat are explained by the predictors in the aforementioned model, which are the socio-demographic variables. According to the aforementioned model, Caucasians are 39 percent more likely than other ethnic groups to experience physical fatigue at work and the odds of this happening to them are 1.390. Several studies mentioned that outdoor workers who are physically exhausted are more vulnerable to safety and health hazards (Song and Zhang 2022). The number of accidents on construction sites also rises when workers engage in unsafe practices (Kazar and Comu 2021). The variation in reported disorders from heat illness is significantly influenced by ethnicity. Except for a few studies focusing on the construction sector, inconsistencies heat-related illnesses based on ethnicities have been identified in other occupational sectors (Gubernot et al., 2015). Depending on the work environment, employees who perform outside have a higher chance of experiencing physical fatigue than those who perform indoors. This variation is estimated to be about 76% higher than workers involved in indoor work activities.

The above model suggests that workers who operate in extremely hot environments are likely to experience minor injuries as a result of working in unfavorable settings, and it was found that this risk was significant based on the construction sector and their working conditions. When compared to workers in the residential sector, the odds of a worker from the commercial and infrastructure sectors experiencing minor injuries are, respectively, 25.3% and 22.4% higher. The output of the model suggests that indoor workers also experience workplace injuries in construction industry.

Construction workers' respiratory health varies in different ways, and it is explained by some of the socio-demographic variables included as predictors in this study. The odds of a male construction worker undergoing respiratory related illnesses were found to be 1.729, or 72.9 percent higher than those of their female counterparts. This may also be explained by the fact that, majority of the times, male construction employees may perform more strenuous manual labor in the field than their female counterparts. A few studies in the literature found that women were more susceptible than men, but the conclusions were general and did not apply specifically to construction workers (Gronlund et al., 2016; Song et al., 2018). This inconsistency may, however, also be caused by the greater proportion of men who labor in the fields. Compared to workers from other sectors, residential construction workers are 21.6 percent more likely to experience respiratory health issues than workers from other sectors. Furthermore, it was identified that construction workers who engage in outdoor activities have 85,1% higher possibilities of developing respiratory health issues than their counterparts. This is due to the fact that outdoor employees are more susceptible to extreme weather conditions and poor air quality than their counterparts performing in an indoor environment. This finding is also corroborated by existing literature studies that present a significant correlation between outdoor workers' poor respiratory health conditions and their exposure to extreme temperatures (Applebaum et al., 2016).

7.9. Conclusion

Construction workers risk their health & wellbeing by working in an uncontrolled thermal environment. As a result, this study highlighted a number of health issues that construction workers face as well as the effects that harsh weather imposes on workers based on various demographic factors. To better understand the difficulties faced by construction workers when exposed to hot temperatures, an online questionnaire survey was distributed to collect data on workers' experiences of various health challenges. The regression model developed based on the data gathered from the survey showed that the workers experiencing physical fatigue, respiratory issues and injuries in hot weather conditions when performing construction activities depend on their demographic traits. Workers involved in outdoor activities are more likely to experience physical fatigue and respiratory issues than workers performing in indoor environment. Male construction workers are likely to experience respiratory related health issues than female counterparts. Workers belonging to industrial and commercial sectors of construction industry are more likely to experience injuries than workers in residential sector. These findings can support in the development of measures aimed specifically at at-risk workers. It is critical to distinguish those who are more susceptible to heat so that workplace safety can be considerably increased. Morbidities and fatalities associated with extreme temperatures can be decreased through increasing preparedness measures and limiting the exposure. The results of this pilot study were based on the self-reported responses provided by the construction workers. The result of this study therefore requires further evidence based on real-time data and draws to the limitation that the findings are based on the empirical results. Future research would greatly strengthen the body of knowledge if it was based on real-time monitoring, constituting a larger sample size with detailed analyses. It is crucial to consider the individuals who are at risk in construction sector and how to effectively lower the harmful health effects of exposure to excessive heat on these workers. The findings of this study will assist industry professionals in recognizing the health concerns faced by construction workers and in the development of effective welfare policies.

CHAPTER 8

EFFECT OF COLD TEMPERATURES ON HEALTH AND SAFETY OF CONSTRUCTION WORKERS

8.1. Abstract

Cold weather conditions create serious safety and health hazards in outdoor working populations. Construction sector is highly streamlined towards outdoor activities. Laborers involved in construction sector are often exposed to extreme weather events, risking their health and safety. Worker productivity decreases, exposed individuals are at risk of developing several health problems, workplace injuries and workplace safety is compromised. This creates a need to explore the various health problems and safety issues experienced by outdoor construction workers. A predictive model that can identify workers who are more susceptible to various health issues caused in cold environment has to be developed to identify and protect workers at risk. Towards this goal, a thorough literature review was conducted to identify the potential health challenges followed by developing a questionnaire survey. The survey distribution yielded 100 responses in total. The gathered data was used to analyze the health, safety challenges experienced by construction workers, and to predict susceptible workers in cold weather conditions by taking various demographic factors into consideration. The results of the study revealed that the construction workers experiencing cold weather injuries like freezing of body parts varied based on demographic factors such as gender, ethnicity, and type of sector the workers are involved in. Respiratory issues which are one of the most common problems during cold weather, varied with gender and work environment. The results obtained will help professionals and senior associates in construction area to develop preventive measures for workers performing in cold weather.

Keywords: Extreme weather, safety, physical health, cold weather, construction workers

8.2. Introduction

The number of non-fatal and fatal injuries are increasing every year. Approximately 270 million injuries have been reported worldwide (Morabito et al., 2014). Workplace injuries are increasing everyday resulting in increased number of absent days in work. These kind of situations creates an impact in the economic conditions by reducing the productivity and increasing the related costs (Habibi et al., 2019; Kermanshachi et al., 2020; Karthick et al., 2022c). Outdoor workers experience more hazards than workers performing in temperature-controlled environments and are known to have direct influence on the output of the work and increases stress. Recent studies on weather related effects in workplace have identified that, there is a percent increase in workplace injuries for every percent variation in the ambient temperature. The risk for occupational injuries increases as the optimal temperature increases or decreases significantly (Fatima et al., 2022; Karthick et al., 2022d; Pamidimukkala et al., 2022d). The risk for occupational injuries in cold temperatures were almost known to increase by two times in outdoor working conditions especially below freezing temperatures (Safapour and Kermanshachi 2020; Fatima et al., 2022).

When workers are exposed to outdoor temperatures, they are prone to some of the various health hazards such as: hypothermia, dexterity in handling tools, thermal discomfort (Karthick et al., 2022a; Karthick et al., 2022b). These issues might father lead to occupational injuries (Schulte and Chun 2009; Karthick et al., 2021e). Intense cold exposure is believed to be more because of lack of sufficient protective clothing, and extended exposure duration. Cold temperatures are known to create more mortalities every year than hot temperatures. Almost, 63% of weather-connected fatalities are from cold temperatures (Berko et al., 2014; Sugg et al., 2019). Increased hospitalizations for hypothermia, which is more common in cold weather, is higher than hyperthermia which is caused in hot weather conditions. Given the intensity of the effects of cold temperatures, however, there are only few studies available which explored the relation of cold temperatures and outdoor workers' health and safety (Allen and Sheridan 2018; Sugg et al., 2019). The consequences of cold temperature on health of humans are considered complex as it also interacts with pre-existing medical conditions. Due to this reason, there are less studies focusing upon the impacts of cold temperatures in occupational setting (Kinney et al., 2015; Sugg et al., 2019).

Health problems of performing in outdoors during cold temperatures include respiratory issues, cold stress, freezing of tissues often known by frostbite, and physical fatigue (Angelova 2017; Karthick et al., 2022g). Cold temperatures not only result in physical health problems but also results in mental health issues like reduced thinking ability, inability to concentrate and mental fatigue (Kiefer et al., 2016; Safapour et al., 2019a; Rouhanizadeh and Kermanshachi 2021). The exposed working population is not uniformly affected by the effects of cold temperatures. The challenges they experience may vary based on various demographic conditions. Certain group of exposed individuals could be more vulnerable than others (Conlon et al., 2011). Identifying these individuals can help regulatory bodies to develop welfare and preventive measures (Safapour et al., 2018; Marinaccio et al., 2019; Karthick et al., 2022f). However, studies focusing on vulnerable workers in cold weather conditions especially for construction sector are very scant compared to hot weather conditions. Also, stringent standards governing workers' safety from weather related hazards are not specific and well outlined (Kiefer et al., 2016; Pamidimukkala and Kermanshachi 2022c). Therefore, this study aims to identify the different health problems faced in the construction sector when working in cold temperatures and also to develop a model for few health problems reported by construction workers by taking demographic characteristics into consideration. The results of this study will help managers in construction sector and law makers to detect the health problems and develop strategies to overcome such hazards.

8.3. Literature Review

8.3.1. Effects of Cold on Outdoor Workers

In cold temperatures, the physiology of an exposed individual tries to thermoregulate by attempting to sustain internal body heat. However, when the body could not trap sufficient heat, the core body temperature begins to lower resulting in cold stress (DeGroot and Kenney 2007; Osilla et al, 2018). During this process, initially the extremities begin to cool down and as more heat is lost from the body, symptoms like shallow breathing and shivering may appear. Once these symptoms begin to manifest, it is important to identify such individuals and remove them from workplace. Otherwise, the exposed individual could experience serious health effects such as cardiac arrest (Analitis et al., 2008; Conlon et al., 2011). Cold temperatures increase discomfort, reduces workers' performance, and increases health problems (Mäkinen et al., 2006; Karthick et al., 2022h).

The definition of cold has been stated by various studies in different ways. One of the studies defined cold in workplace perspective based on international standards as "workplaces that have temperatures less than 10 degrees Celsius to 15 degrees Celsius could be considered as a cold workplace" (Mäkinen and Hassi 2011). The impacts of exposure to cold depends on multiple factors. Some of these factors are the cold's intensity, intensity of physical activity, type and quality of protective clothing, and several other individual aspects like age, medical conditions, gender, fitness of exposed individual (Stocks et al., 2004). Individuals who do not have sufficient protective clothing are at higher risk of experiencing frostbite, numbness, trench foot conditions and necrosis as there is higher heat loss from the body due to exposure (Angelova 2017).

Frostbite is a condition of tissue injury resulting from prolong cold exposure below the freezing temperature. However, in recent years, frostbite has become common when exposed to cold temperatures due to increased number of outdoor activities. Hands, feet, cheeks, and other parts of face could also be affected (Zhao et al., 2020). Numbness is a sensory feeling and cold temperatures might also cause fingers to become stiff (Inaba and Mirbod 2010). This affects the workers' performance in handling tools. Trench foot, also known by immersion foot is a non-freezing cold injury usually caused due to exposure of feet in cold water which might arise due to improper covering of the feet (Atenstaedt 2006). In construction, workers might have to perform manual activities for extended duration that involves standing in damp and cold mud, and water. An example of such activity is foundation excavation (Tummalapudi et al. 2020; Uter and Kanerva 2020). Necrosis develops during extreme stages of frostbite when there is no blood flow to the tissue. Skin problems and respiratory issues are also common during cold weather. Skin problems may include dry, psoriasis, dermatitis and itchy skin (Mäkinen and Hassi 2009; Karthick et al., 2022). Respiratory issues could be asthma, dry cough, bronchitis, lung disease, problems in the upper and lower respiratory tracts. In cold weather, cardiological problems are also on the rise due to increase in cardiac strain as the body tries to maintain the core body temperature (Kotaniemi 2002; Castellani et al., 2010; Rouhanizadeh and Kermanshachi 2019).

Cold temperatures also increase the Musculo-skeletal disorders. The laborious activity in construction induces fatigue and the presence of cold may further exacerbate the Musculo-skeletal pain. These include neck issues, shoulder pain, issues in the lower back and various other parts of body(Burström et al., 2013). There is increase in the blood pressure often identified as hypertension. Individuals with pre-existing medical condition on hypertension may further be exacerbated with exposure to cold for prolonged duration (Mäkinen and Hassi 2009). Slips and fall related accidents increase during cold temperatures due to slippery surfaces (Bonafede et al, 2016).

8.3.2. Individual Vulnerabilities Towards Cold Temperatures

Impact of cold on exposed population varies based on various socio-demographic characteristics. Identifying these factors can support in developing efficient strategies (Haman et al., 2022; Pamidimukkala and Kermanshachi 2022b). Older individuals above 65 years in age are more prone to health problems related to cold due to slower thermoregulation. Few studies also stated that younger individuals are also vulnerable to the effects of cold on their health. Females who are older compared to males are prone to cold related health problems (Conlon et al., 2011; Kingma et al., 2011; Zeka et al., 2014). Individuals who are not used to exposure to cold temperatures could also be more severely impacted and such individuals require acclimatization practices. In regard to ethnicity, population with African origin could be susceptible to cold injuries than other ethnicities (Burgess and Macfarlane 2009; Maley et al., 2014). Identification of vulnerable individuals can help in tailoring strategies and developing more efficient preventive measures.

8.4. Research Methodology

In the first stage of the methodology, complete literature review was performed to identify the current studies that focused on the relation between cold temperatures and health problems. Several search engines and medical database were used in this process. Various key words such as "health challenges", "cold temperature", "occupational injuries", "construction workers", "outdoor" and "safety issues" were searched in different combinations to identify the possible health challenges experienced in cold temperatures. In the next stage, the factors and challenges from the literature review that were identified were used to make a detailed questionnaire survey for the purpose of data collection. Online survey development tool was used in the process. The survey was distributed through a link, to various workers in the construction industry through emails. The responses received from the survey was then gathered for preliminary data analysis. In the preliminary data analysis, the dataset was cleaned, and univariate analyses were performed. This data was then visualized, and a predictive model was developed based on various demographic factors for cold weather health problems. The Figure 8.1. below represents the research methodology adopted in this study.

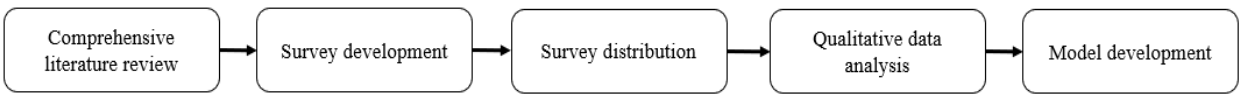


Figure 8. 1. Research Methodology

8.5. Survey Development and Distribution

An online questionnaire was created based on the comprehensive literature study. The survey was made using online survey development tool known as '"QuestionPro". The survey comprised of 25 questions with several sub-sections. Majority of the questions in the survey were asked in Likert scale format. In the initial part of the survey the demographic details of the survey participants were collected. These include respondents age, gender, ethnicity, their working environment, and the type of construction sector. In the second part of the survey, questions were asked to understand the challenges to the physical health of the respondents when performing in cold weather conditions. In the third part of the survey, questions were asked to identify the possible mental health issues the workers experienced when working in cold weather conditions. The fourth part of the survey dealt with questions that helped in understanding the respondents behavior. These include attributes such as drinking and smoking habits. The survey was distributed to all the states in the United States, to more than 200 participants and yielded over 100 responses. The response rate obtained was 41%. Individuals who are older than 18 years and working in the construction sector were the only inclusion criteria outlined to take part in the survey. The participants were not compensated in any means. The data collected from the survey was gathered for visualization and further analyses. The Figure 8.2. below provides an example of the questions asked in the survey.

Demographic questions

- Please specify your age?
- Please specify the type of construction sector you are involved in?
- Please specify your responsibility in construction industry?

Workforce cold weather challenges

- How frequently have you experienced physical injuries when working in cold weather conditions?
- How frequently does wearing a personal protective clothing create discomfort when working in cold weather conditions?
- How frequently have you ever felt inability to concentrate when working in extreme cold weather conditions?

Figure 8. 2. Sample of Questions from the Survey

8.6. Demographic Data Analysis

The survey yielded 100 responses in total. The collected responses were then demographically analyzed. Majority of the survey respondents were in the category of males, which constituted of about 87% while 13% of the responses were from females. Analyzing the survey responses based on age revealed that majority of the respondents were older than the age of 40 where, 20% of those who answered were between 41-50, 19% of the answers were 51-60 years, and 20% of those who answered were greater than 60 years. Respondents between 31-40 years of age were only 12% while 29% of the respondents were between 21-30 years of age. The Table 8.1. below illustrates the descriptive data analysis of the survey participants in various categories.

Table 8. 1. Demographic Characteristics of the Respondents

Characteristics of respondents	Percentage in sample
Age	21-30 years – 29% 31-40 years – 12% 41-50 years – 20% 51-60 years – 19% Above 60 years- 20%

Gender	Male – 87% Female – 13%
Ethnicity	Caucasians – 63% Asians – 30% Hispanic – 4% Other – 3%
Work experience	Below 5 years – 23% 5 to 10 years – 17% 10 to 15 years – 5% 15 to 20 years – 11% More than 20 years – 44%

Based on ethnicity, majority of the 63% of the respondents were Caucasians, 30% of the respondents were Asians while 4% of the respondents were of Hispanic origin. The survey distribution gathered responses with wide range of work experience in construction sector. Workers who had lesser than 5 years of work experience constituted about 23%. Around 17% of the answers had 5 to 10 years of work experience in construction sector, and 44% of the respondents had more than 20 years of work experience in construction. The Table 1 above illustrates the descriptive data analysis of the survey participants in various categories.

8.7. Model Development

The data collected from the survey was entered into SPSS, a statistical software used to perform statistical analysis and for model building purposes. The dataset was cleaned by removing all the outliers, followed by data visualization. The modelling technique used was logistic regression as majority of the data gathered were based on Likert scales. Since the dataset had categorical outcome variables, logistic regression would be the best fit for the data. Therefore, the logistic regression model will predict the outcome of a specific health problem experienced by a construction worker in cold weather conditions. Epidemiological research areas frequently use logistic modelling techniques to predict the occurrence of certain disease or a health problem (Wong 2004). Recently several studies have adopted this technique in the area of public health prediction. Also, studies with a focus of population health outcome and extreme temperatures have adopted logistic regression modelling techniques (Nitschke et al., 2013; Lohrey et al., 2021). This study developed simple logistic models for the following health problems in cold weather: (1) freezing of exposed body parts, (2) respiratory issues based on various demographic features. The logistic function of logistic regression model is presented in the Equation (1) below.

$$\ln\left(\frac{\Pi}{1-\Pi}\right) = \alpha + \beta X \qquad (1)$$

In the above equation, the variable on the left is known as logit, the log-odds function. α in the equation refers to the Y-intercept. β refers to the slope. Π denotes the probability of the outcome and X in the equation represents the categorical variable (Abdulqader 2017).

8.7.1. Assumptions Followed for Logistic Regression Model

In order to choose logistic regression model certain assumptions, need to be followed. The assumptions followed are: (1) The dependent variable or the categorical variable in the model is not continuous. It is in categorical scale, (2) There are at least more than one independent variable in the model, (3) There is no linearity, and the observed variables are independent (Field 2009; Abdulqader 2017).

8.8. Results and Discussion

8.8.1. Model Output

The data entered in the SPSS were defined and organized for modelling. The dependent variables were the presence of health outcome and the independent variables in the model were demographic variables. Variables consisting of more than one category was dummy coded. Logistic regression was carried out in a stepwise approach. The results below in Table 8.2. provides the model output.

Table 8. 2. Model Output

#	Predictors	Dependent variable			
		Respiratory issues		Freezing of exposed parts	
		Sig	Exp (B)	Sig	Exp (B)
1.	Gender	0.037**	1.697	0.020**	1.439
2.	Age	0.080*	0.778	0.205	1.608
3.	Ethnicity=Hispanic	0.316	1.006	0.890	0.110
4.	Ethnicity=Caucasian	0.745	0.106	0.559	0.342
5.	Ethnicity=Asian	0.763	0.091	0.288	1.129
6.	Type of sector=Residential	0.489	0.478	0.910	0.214
7.	Type of sector=Commercial	0.778	0.080	0.364	0823
8.	Type of sector=Infrastructure	0.403	0.015	0.147	2.107
9.	Work environment=Outdoor	0.041**	1.141	0.032**	1.217
10.	Work environment=Indoor	0.557	0.346	0.703	0.146

Note: ** denotes 95% level of confidence; * denotes 90% level of confidence.

8.8.2. Model Interpretation and Discussion

The cold weather health problems, respiratory issues and freezing of body parts are explained by the demographic predictors in the above model. The above model can be interpreted as the odds of a male construction worker experiencing respiratory issues is 1.697, which in terms of percent could be interpreted as 69.7% higher than female counterparts. This contradicts with some of the existing studies as they have identified that respiratory issues in cold weather are more common in females (Mäkinen and Hassi 2009). The model revealed that the odds of elder workers experiencing respiratory issues is 77.8% higher than younger individuals. This supports with the existing literatures that older workers are more likely to experience respiratory related issues in cold weather than younger workers (Mäkinen and Hassi 2009). Workers performing in outdoor environment are 14.1% more likely to experience respiratory issues than workers in indoor environment. This is because workers laboring in outdoors are directly to exposed to breathing cold air resulting in respiratory issues. The odds of a male worker experiencing freezing of body parts while performing in cold temperature is 1.439, which in terms of percent could be interpreted as 43.9% higher than female counterparts. This could also be attributed to the reason that more male workers are employed in the field than female workers. The odds of a construction workers majorly performing in an outdoor environment is 21.7% more likely to experiencing freezing of body parts than workers who perform in an indoor environment. The results identified in this study corroborate with the existing literature that outdoor workers, also from construction sector are more prone to cold related injuries and health problems and require efficient preventive measures to protect them from weather related hazards.

8.9. Conclusion

Cold temperatures affect the health of overall population and more specifically outdoor workers. Construction workers could be the most affected as they need to perform majority of their activities in thermally imbalanced environment. Due to this, it is imperative to understand the various health and safety problems experienced by workers in these sectors so that an effective solution can be developed. To this end, a detailed questionnaire survey was created and distributed. The responses collected from the survey were analyzed to find the health issues encountered by these workers when performing in extreme temperatures. The results revealed that older workers and male workers are more likely to experience respiratory related health problems in cold weather than younger workers and female workers. Freezing of body parts were found to vary based on gender, and work environment. Therefore, the health problems experienced due to cold weather are wide and its impact vary based on demographic factors. Identifying these factors can help in developing specific strategies and preventive measures. As the results of this study are based on empirical results, furthermore definitive conclusion needs to be drawn based on real-time evidence with a large sample and not solely on empirical results. A more detailed study in the future based on a large sample is recommended for stronger evidence and to ascertain the importance. The results identified in this study will be helpful to construction practitioners in identifying workers at risk and develop strategies accordingly.

CHAPTER 9

CONCLUSION AND RECOMMEDNATIONS

9.1. Conclusion

Construction workers are severely affected upon exposure to extreme temperature. Therefore, this study aimed to understand the various challenges experienced by the workers in construction industry when performing in unfavorable weather conditions. To achieve this objective a comprehensive literature review was performed which helped in identifying the various challenges that individuals could experience upon exposure to hot and cold temperatures. The identified challenges were grouped into two categories as physical health challenges and mental health challenges for hot and cold weather conditions. Twenty-two physical health challenges were identified, of which eleven physical health challenges were for hot weather conditions and ten of them were for cold weather conditions. These challenges can manifest in the exposed individuals as various health complications. Some of the physical health challenges includes heat stroke, heat edema, chronic kidney diseases, heat rash in hot weather conditions and frostbite, Musculo-skeletal disorders, hypothermia, and respiratory issues in cold weather conditions. Sixteen mental health challenges were identified based on literature review for hot and cold weather conditions. Few of the mental health challenges experienced by individuals when performing in extreme temperatures are psychological stress, hallucination, lack of mental coordination, depression, and anxiety. These mental health challenges might create impact on the workplace such as reduced performance, productivity and might further exacerbate their health problems.

This study also identified the various health challenges that were significant based on various physiological indicators and personal factors. To achieve the objectives of this study a questionnaire survey was developed to collect data on the various challenges experienced by construction workers when performing in extreme temperatures. The questionnaire was developed based on the comprehensive literature review. The survey constituted of 26 questions with various sub-categories. These are demographic questions, questions that helped in identifying the physical health challenges in hot and cold weather conditions, questions that helped in identifying the mental health challenges in hot and cold weather conditions, behavioral questions that helped in identifying the workers' drinking and smoking characteristics. The link of the survey was distributed to workers in construction industry through emails. After several rounds of survey distribution all over the United States, the survey yielded 100 responses. The data gathered from the survey was then descriptively and quantitatively analyzed. Quantitative analysis of the survey was carried out using non-parametric statistical test to understand the significance of the challenges based on indicators such as heart rate, blood pressure, acclimatization of the workers and workers' clothing comfort. Minor workplace injuries and major accidents occur irrespective of the heart rate, but it is an indicator of physical fatigue and respiratory problems. The results infer that challenges such as dehydration, sweating, and physical fatigue are influenced by whether the workers are acclimatized to their working environment. Increased sweating, heat edema and heat cramps were common among workers in hot weather conditions based on the comfort of their clothing. The conclusions drawn from this study support the following basic tenets of the existing literature: (1) it is important for workers to be acclimatized to the weather conditions on construction sites, (2) clothing properties influence the challenges faced by workers in extreme hot weather, and (3) monitoring workers' heart rates and blood pressure can help prevent heat-related illnesses.

Well acclimatized worker and PPC of right fit are two important personal factors that improves the challenges of working in cold weather conditions. Challenges such as hypothermia, frostbite, freezing of body parts, trenchfoot conditions are perceived differently in acclimatized workers than unacclimatized workers. Acclimatized workers' perception on mental health challenges such as inability to concentrate and frequent mood fluctuation were likely to be different than unacclimatized workers. Workers' perception on challenges such as slips and falls, freezing body parts, physical fatigue are likely to be experienced differently in workers with a comfortable personal protective clothing. Mental challenges like inability to concentrate, need for longer breaks, and metal stress were perceived differently in workers with comfortable protective clothing. Monitoring workers' heart rate when working in cold weather conditions helps in identifying workers who are experiencing cold stress.

Construction sites should implement continuous monitoring health programs and measures, so that the safety of the sites can be increased in extreme weather conditions. Therefore, the results obtained from this study will also be useful in developing a physiological monitoring program that can be used, when WBGT is not possible, and to identify the challenges that workers experience in hot weather conditions so that preventative measures can be developed to protect them.

This study also aimed to develop a regression model to understand the relationship between the various health challenges and the socio-demographic attributes of the exposed individual. The need to this objective is justified by the fact that individuals are not uniformly affected when exposed to extreme temperatures and requires exploration in this area so that effective strategies could be developed. The data gathered from the survey were visualized to perform logistic regression as majority of the data collected were based on likert scales. Logistic regression was performed using statistical software "IBM SPSS Statistics" version 28.0. The results of the regression on physical fatigue revealed that the workers experiencing physical fatigue, respiratory issues and injuries in hot weather conditions when performing construction activities depend on their demographic traits. Workers involved in outdoor activities are more likely to experience physical fatigue and respiratory issues than workers performing in indoor environment. Male construction workers are likely to experience respiratory related health issues than female counterparts. Workers belonging to industrial and commercial sectors of construction industry are more likely to experience injuries than workers in residential sector. The results also revealed that older workers and male workers are more likely to experience respiratory related health problems in cold weather than younger workers and female workers. Freezing of body parts were found to vary based on gender, and work environment. Therefore, the health problems experienced due to cold weather are wide and its impact vary based on demographic factors. These findings can support in the development of measures aimed specifically at at-risk workers. It is critical to distinguish those who are more susceptible to heat so that workplace safety can be considerably increased. Morbidities and fatalities associated with extreme temperatures can be decreased through increasing preparedness measures and limiting the exposure.

9.2. Limitations and Recommendations

The study helps in understanding the various health challenges experienced by workers in construction sector when exposed to severe hot and cold temperatures. However, there are few limitations that need to be presented. The results from this study are based on empirical results, and based on self-reported survey responses, therefore it is highly recommended that real time evidence with more data from a large proportionate sample could be more reliable than just empirical results. Various other data collection techniques like interviewing the workers performing at construction sites could be performed as additional data source than just relying on online survey technique. Another limitation is that the responses could be subjective to bias as they are self-reported responses. Therefore, in future, real-time data could be gathered for more reliable outcomes.

This study could be developed further in various ways. Some of the possible scope for future work are listed below:

1. The study can be built further by exploring the existing techniques and welfare measures carried out at various construction sites in regard to exposure of the working crew at extreme temperatures. The efficiency of current regulations and practical recommendations for workers performing at extreme temperatures can be provided from management perspective in future.
2. The outcomes of this study can be further corroborated with more evidence obtained from quantitative data (which can be gathered from health websites) such as the annual weather-related morbidities and mortalities of outdoor occupational cohort.
3. The study can be further expanded by developing a risk-assessment checklist for employers to monitor the workers' health when exposed to extreme temperatures.

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APPENDIX A

Invitation to Participate in the Survey

Email Subject:

Your Input Needed: Impact of Extreme Weather Conditions on Health of Construction Workforce

Body of the Email:

Greetings,

I'm writing to request your participation in a brief survey, which will be used in a project of great importance. With your experience and knowledge, we believe that you'll be able to help us gain valuable insight in our research on the topic: Impact of Extreme Weather Conditions on Health of Construction Workforce. This research aims to help us understand the health challenges faced by construction workers in extreme weather conditions.

Your participation in the survey is voluntary, and your responses are completely confidential. If you have any questions or concerns about the study, please feel free to email the Project Principal Investigator, Dr. Sherri Kermanshachi at sharareh.kermanshachi@uta.edu.

We hope that you will take the time to answer the questions by January 15th, 2022. The survey is brief and completing the survey should take no longer than 10 minutes. Thank you in advance for your help with this valuable study. To begin the survey, please click on the link below:

https://utaedu.questionpro.com/t/ARYJ7ZjacD

APPENDIX B

Survey

<u>Demographic Information</u>

Q1. Please specify your job title?

- ☐ Construction laborer
- ☐ Building inspector
- ☐ Equipment operator
- ☐ Site manager
- ☐ Field engineer
- ☐ Electrician
- ☐ Plumber
- ☐ Superintendent
- ☐ Other (Please specify) ___________ ___________

Q2. Please specify your age range.

- ☐ 18 – 20 years
- ☐ 21 – 30 years
- ☐ 31 – 40 years
- ☐ 41 – 50 years
- ☐ 51- 60 years
- ☐ 60+ years

Q3. Please specify your years of experience you have in working in the construction industry.

- ☐ Less than 5 years
- ☐ 5 years – 10 years
- ☐ 10 years – 15 years
- ☐ 15 years – 20 years
- ☐ 20 years – 25 years
- ☐ 25 years – 30 years
- ☐ More than 30 years

Q4. Please specify your annual income range.

- ☐ Less than $20K
- ☐ $20K - $30K
- ☐ $30K - $40K
- ☐ $40K - $50K
- ☐ $50K - $60K
- ☐ $60K - $70K
- ☐ $70K - $80K
- ☐ Above $80K

Q5. Please specify the gender you identify as.

- ☐ Male
- ☐ Female
- ☐ Prefer not to answer

Q6. Please specify your ethnicity.

- ☐ Hispanic
- ☐ White
- ☐ American Indian and Alaskan Native
- ☐ Native Hawaiian and other Pacific Islander
- ☐ African American
- ☐ Asian
- ☐ Other (Please specify) ___________ ___________

Q7. Please specify the type of construction sector you work in.

- ☐ Residential
- ☐ Commercial
- ☐ Industrial
- ☐ Infrastructure (Transportation, Water, Communication, Waste management, etc.)
- ☐ Heavy construction
- ☐ Other (Please specify) __________ __________

Q8. Please specify your responsibility in the construction industry.

- ☐ Scaffolding
- ☐ Roofing
- ☐ Concreting
- ☐ Steel fixing and bar bending
- ☐ Plumbing
- ☐ Formwork
- ☐ Other (Please specify) __________ __________

Nature of Work Environment

Q9. Please specify the majority of your working environment.

- ☐ Indoor work
- ☐ Outdoor work
- ☐ Combination of both

Q10. Please specify the condition of your working environment (Select as much as applies)?

- ☐ Extremely hot
- ☐ Moderately hot
- ☐ Extremely cold
- ☐ Moderately cold
- ☐ High humidity
- ☐ Low humidity
- ☐ None of the above

Q11. Are you used to the temperature and humidity of your working condition?

- ☐ Yes
- ☐ No

State of Health

Q12. Please specify if you have any pre-existing physical pain in the body due to construction work?

- ☐ Back pain
- ☐ Shoulder pain
- ☐ Muscular pain
- ☐ Other (Please specify) __________ __________

Q13. Have you been diagnosed with any heart problems due to your working conditions?

- ☐ Yes
- ☐ No

Q14. How frequently do you consult a doctor or visit a healthcare facility annually?

- ☐ Never
- ☐ Rarely
- ☐ Occasionally

- ☐ Sometimes
- ☐ Frequently
- ☐ Usually
- ☐ Always

Q15. Please select the approximate annual cost associated with healthcare visits?

- ☐ None-No Healthcare Visits
- ☐ Less than $250
- ☐ Between $250 and $500
- ☐ Between $500 and $1000
- ☐ Between $1000 and $2500
- ☐ Between $2500 and $5000
- ☐ More than $5000

Health Challenges due to Hot Weather

Q16. Please specify how frequently have you experienced the followings while working in hot weather conditions?

	Never	Rarely	Occasionally	Sometimes	Frequently	Usually	Always
A. How frequently does wearing Personal Protective Equipment (PPE) and Personal Protective Clothing (PPC) create any discomfort when working in hot weather?	❑	❑	❑	❑	❑	❑	❑
B. How frequently you feel drained while performing the same task in extreme hot environment?	❑	❑	❑	❑	❑	❑	❑
C. How frequently have you encountered any major accidents/ burns/ amputations or serious injuries at workplace?	❑	❑	❑	❑	❑	❑	❑
D. How frequently have you been injured physically while working in hot environment (Minor wounds or any other physical injuries)?	❑	❑	❑	❑	❑	❑	❑
E. How often do you get respiratory problems like asthma while working in hot environment?	❑	❑	❑	❑	❑	❑	❑
F. How frequently do you excessively sweat while working in extreme hot weather conditions?	❑	❑	❑	❑	❑	❑	❑
G. How frequently have you experienced any skin problems such as heat rash or skin irritation while working in hot environment?	❑	❑	❑	❑	❑	❑	❑
H. How frequently have you felt increase in heart rate when working in hot weather?	❑	❑	❑	❑	❑	❑	❑
I. How frequently have you experienced physical fatigue due to working in hot weather conditions?	❑	❑	❑	❑	❑	❑	❑

Q17. How frequently have you experienced the followings while working in hot weather conditions?*Heat edema: The swelling of feet or hands when a person sits or stands for a long time in a hot environment is known as heat edema.**Heat cramps: These are painful muscle cramps. Muscles may spasm or jerk involuntarily while working in a hot environment.***Hypertension: Blood pressure above 140/90 is defined as hypertension.

	Never	Rarely	Occasionally	Sometimes	Frequently	Usually	Always

A. *Heat edema	❑	❑	❑	❑	❑	❑	❑
B. **Heat cramps	❑	❑	❑	❑	❑	❑	❑
C. Kidney disease	❑	❑	❑	❑	❑	❑	❑
D. Increased blood sugar	❑	❑	❑	❑	❑	❑	❑
E. ***Hypertension	❑	❑	❑	❑	❑	❑	❑

Health Challenges due to Cold Weather

Q18. How frequently have you experienced the followings while working in cold weather conditions?*Hypothermia: When your body is exposed to cold weather for long duration, body temperature may drop below 95 F. Symptoms of hypothermia include shivering, weak pulse, lack of coordination, lack of energy etc.**Frostbite: When your body parts such as fingers and toes are exposed to extreme cold weather, outer skin and underlying tissue cells freeze. The skin gets very cold, then numb, hard, and pale. ***Trenchfoot/Immersion foot: Trench foot, also known as immersion foot, is an injury of the feet resulting from prolonged exposure to wet and cold conditions. Symptoms include numbness, swelling, leg cramps etc.

	Never	Rarely	Occasionally	Sometimes	Frequently	Usually	Always
A. Muscle fatigue	❑	❑	❑	❑	❑	❑	❑
B. Neck pain	❑	❑	❑	❑	❑	❑	❑
C. Lower back pain	❑	❑	❑	❑	❑	❑	❑
D. Complete body pain	❑	❑	❑	❑	❑	❑	❑
E. Inflammation	❑	❑	❑	❑	❑	❑	❑
F. Slips and falls	❑	❑	❑	❑	❑	❑	❑
G. *Hypothermia	❑	❑	❑	❑	❑	❑	❑
H. **Frostbite	❑	❑	❑	❑	❑	❑	❑
I. ***Trenchfoot/Immersion foot	❑	❑	❑	❑	❑	❑	❑

Q19. How frequently have you experienced the followings while working in cold weather conditions?

	Never	Rarely	Occasionally	Sometimes	Frequently	Usually	Always
A. How frequently have you experienced skin disorders such as dry skin, swelling, itching or any other related skin injuries while working in cold weather?	❑	❑	❑	❑	❑	❑	❑
B. How frequently have you faced inability to perform work due to freezing of toes and numbness in fingers?	❑	❑	❑	❑	❑	❑	❑
C. How frequently does wearing Personal Protective Equipment (PPE) and Personal Protective Clothing (PPC) create any discomfort when working in cold weather?	❑	❑	❑	❑	❑	❑	❑
D. How frequently have you slipped and fell due to cold working weather?	❑	❑	❑	❑	❑	❑	❑
E. How often do you get respiratory problems like asthma while working in cold environment?	❑	❑	❑	❑	❑	❑	❑
F. How frequently have you felt increase in your heart rate due to working in cold weather?	❑	❑	❑	❑	❑	❑	❑
G. How frequently have you experienced major physical injuries like accidents while working in cold weather?	❑	❑	❑	❑	❑	❑	❑
H. How frequently have you experienced	❑	❑	❑	❑	❑	❑	❑

severe wrist pain due to working in cold weather conditions?							
I. How frequently have you experienced increase in muscular load while performing any repetitive task in a cold working environment?	❑	❑	❑	❑	❑	❑	❑
J. How frequently have you experienced diarrhea or bad abdominal condition due to working in cold environment?	❑	❑	❑	❑	❑	❑	❑
K. How frequently have you experienced physical fatigue due to working in cold weather?	❑	❑	❑	❑	❑	❑	❑

<u>Other Health Challenges</u>

Q20. How frequently have you experienced the followings while working in hot weather conditions?

	Never	Rarely	Occasionally	Sometimes	Frequently	Usually	Always
A. How frequently have you felt mood changes, depression, or other mental problems due to working in hot weather conditions?	❑	❑	❑	❑	❑	❑	❑
B. How frequently have you ever felt inability to concentrate due to working in extreme hot weather conditions?	❑	❑	❑	❑	❑	❑	❑
C. How frequently have you experienced a lack of control on temper/felt impatient due to working in hot weather conditions?	❑	❑	❑	❑	❑	❑	❑

Q21. How frequently have you experienced the followings while working in cold weather conditions?

	Never	Rarely	Occasionally	Sometimes	Frequently	Usually	Always
A. How frequently have you felt lack of concentration at the work you perform due to working in extreme cold environment?	❑	❑	❑	❑	❑	❑	❑
B. How frequently have you ever felt tiredness in hands while operating any hand tools or equipment, while working in cold weather conditions?	❑	❑	❑	❑	❑	❑	❑
C. How frequently have you felt mentally stressed due to working in cold weather conditions?	❑	❑	❑	❑	❑	❑	❑
D. How frequently have you felt mood changes, depression, or other mental problems due to working in cold weather conditions?	❑	❑	❑	❑	❑	❑	❑

Q22. How frequently have you experienced the followings?

	Never	Rarely	Occasionally	Sometimes	Frequently	Usually	Always
A. How frequently do you smoke due to your working conditions?	❑	❑	❑	❑	❑	❑	❑
B. How frequently do you consume alcoholic drinks due to your working conditions?	❑	❑	❑	❑	❑	❑	❑

Q23. How familiar are you on the risks associated with working in each of the following weather conditions?

	Strongly unfamiliar	Unfamiliar	Somewhat unfamiliar	Neither familiar nor unfamiliar	Somewhat familiar	Familiar	Strongly familiar
A. Hot weather conditions	❑	❑	❑	❑	❑	❑	❑
B. Cold weather conditions	❑	❑	❑	❑	❑	❑	❑

Q24. Please select your responses for the following:

	Never	Rarely	Occasionally	Sometimes	Frequently	Usually	Always
A. How frequently do you slow down your work while experiencing fatigue in hot weather conditions?	❑	❑	❑	❑	❑	❑	❑
B. How frequently do you require longer breaks while working in hot weather conditions?	❑	❑	❑	❑	❑	❑	❑
C. How frequently do you require longer breaks while working in cold weather conditions?	❑	❑	❑	❑	❑	❑	❑

Q25. How much do you agree that an efficient cold protection plan with optimized working hours or reduced exposure to cold increase your productivity?

- ☐ Strongly disagree
- ☐ Disagree
- ☐ Somewhat disagree
- ☐ Neither agree or disagree
- ☐ Somewhat agree
- ☐ Agree
- ☐ Strongly agree

Q26. How frequently do you discuss your psychological and mental distress with health practitioners, if any?

- ☐ Never
- ☐ Rarely
- ☐ Occasionally
- ☐ Sometimes
- ☐ Frequently
- ☐ Usually
- ☐ Always
- ☐ N/A