POAC'17
Busan, KOREA

Proceedings of the 24th International Conference on
Port and Ocean Engineering under Arctic Conditions
June 11-16, 2017, Busan, Korea

Cold Stress: Safety Issues when Working in Cold Environments

Yonas Zewdu Ayele[1], Abbas Barabadi[1]
[1] Department of Engineering and Safety, UiT The Arctic University of Norway, Tromsø, Norway

ABSTRACT

Exposure to cold environments can be a significant challenge for a person's comfort, for performing a given task in a safe and efficient manner and in the most extreme cases, also for survival. Understanding of the impact of cold exposure to human body is important to make the necessary preventive measures. Further, investigating the negative adverse impact help us to prepare personal protective clothing and equipment (PPC/PPE) and to layout the procedure how to use the PPC/PPE in optimal manner. The purpose of this paper is thus to propose a simplified cold stress analysis methodology, by investigating the risk factors that contribute to cold stress. The central thrust of the paper is to understand the work-related hazards and risks in cold operating environments; and, propose control measures to eliminate or reduce the identified risks.

KEY WORDS: Cold exposure; Cold stress; Risk management; Personal protective equipment

INTRODUCTION

Humans are "designed" to operate in very narrow temperature range. Low temperatures, wind, snow, and darkness reduces cognitive and reasoning abilities and, cognitive errors are more likely to occur. Further, cold environment significantly reduced the effectiveness of the workers, and possibility of mistakes or being inaccurate increases. For instance, since 1994, human error causes 9 out of 10 fatal accidents on the Norwegian continental shelf (NCS) and the main reason is the lack of concentration, which is caused by cold working environment (Aalipour et al., 2016). Moreover, the direct economic costs of work-related (occupational) injuries and illnesses, due to climatic and environmental conditions, on the NCS is estimated between NOK 710 and NOK 1,415 million per year (approximately EUR 91.5 to 172.5 million) (ECON, 2005).

In general, humans who are exposed to extreme cold, or work in cold environments maybe at risk of "Cold Stress". Cold stress is the response of the body to cold temperatures resulting from heat loss and the opposite of heat stress and, kills 20 times as many people as hot weather. (Risikko et al., 2003). Various factors can affect the body's ability to tolerate or maintain internal core body temperatures, which is the operating temperature of human beings. Factors include, the heat generated within the body from the work activity, how we lose heat to the environment (conduction, convection, radiation, evaporative heat loss), environmental

conditions (e.g. air temperature, humidity, air movement), and the clothing worn (Ayele et al., 2015, Risikko et al., 2003). There are two main types of cold stress: whole-body cooling, and local cooling, including extremity cooling, convective skin cooling (wind chill), conductive skin cooling (contact cooling), and cooling of respiratory tract.

Understanding the impact of cold exposure to human body is important to make the necessary preventive measures. In general, decision makers must be able to recognize, how cold weather affects human performance and, consequently adjusts management and operational tools and approaches. The evaluations of these factors can help to have an effective working environment with high level of safety in the harsh, remote and cold environment. Further, investigating the negative adverse impact help us to prepare personal protective clothing /equipment (PPC/PPE) and to layout the procedure how to use the PPC/PPE in optimal manner.

Over the years, a number of work-related (occupational) health and safety hazards assessment models and approaches have been developed, to measure the relative effect of the cold operating environment on the human performance and, evaluate the risk of human error; see e.g. Aalipour et al. (2016), Ayele et al. (2015), Risikko et al. (2003), Jussila et al. (2010), and Mearns et al. (2003). For instance, Ayele et al. (2015) proposed a risk-based approach to eliminate and manage occupational hazards when working in the cold and harsh operational condition and, offered a step-by-step risk reduction measures. Risikko et al. (2003) developed a model for managing cold-related health and safety risks at workplaces. Further, there are several regulations and standards, which define the methods and procedures for evaluating and managing work-related health and performance risks in cold workplaces. One of such standards, for instance, is ISO 15743:2008, Ergonomics of the thermal environment – Cold workplaces – Risk assessment and management.

However, there is a lack of implementation of simplified as well as systematic cold stress analysing methodology. Furthermore, the traditional available tools or methodologies lacks an explicit causal model linking observed behaviour to personal and situational factors, and most of the methodologies are too cumbersome, time-consuming and generalised. Hence, developing a simplified methodology that supports and, facilitates the decision-making process, by measuring the relative effect of the cold operating environment, can offer the solution to filling the gaps that exist in the present cold stress assessment methodologies. The purpose of this paper is thus to propose a simplified cold stress analysis methodology, by analyzing the unique characteristics of cold operating environment and, their effect on human performance. Further, the paper comprise the assessment of potential job hazards, risks of work-related (occupational) injury, and health risks stemming from exposure to harsh environmental factors, such as cold, icing of work surfaces, ice falling from heights, darkness, etc.

The rest of the paper is organized as follows: The simplified cold stress analysis methodology is presented in Section 2. Thereafter, in Section 3, the direct and indirect cold related hazards are summarized. Afterwards, the control measures that can be employed for reducing cold exposure, are depicted in Section 4. Finally, the concluding remarks is presented in Section 5.

PROPOSED COLD STRESS ANALYSIS METHODOLOGY

Cooling influences muscle function greatly, resulting in: decreased muscle strength, slower reaction, poorer endurance, poorer muscle coordination, reduced manual skill (dexterity), and lower rate of muscle contraction (Risikko et al., 2003). Moreover, heat loss and cold experience

affects the mental function in a human and maybe a significant distraction factor. Since, humans have a narrow temperature range in which it works optimally and, at higher and lower temperatures, we act poor. This leads among other things to the increasing number of errors. Figure 1 illustrates the proposed cold stress analysis methodology for investigating work-related hazards in the cold operating environment. The proposed methodology consists of four main steps: *i*) understanding body heat balance concept, *ii*) evaluating direct and indirect cold related hazards, *iii*) analyzing control measures, which can be employed to reduce the negative impact of cold exposure, and *iv*) establishing cold exposure monitoring programme.

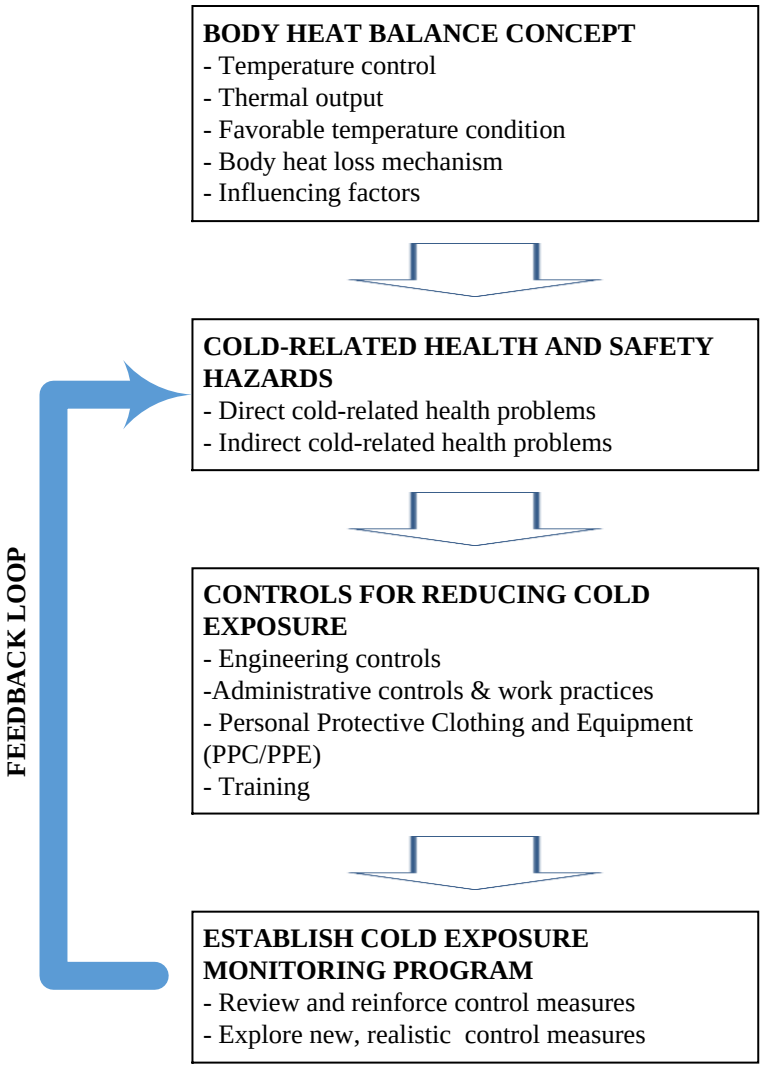
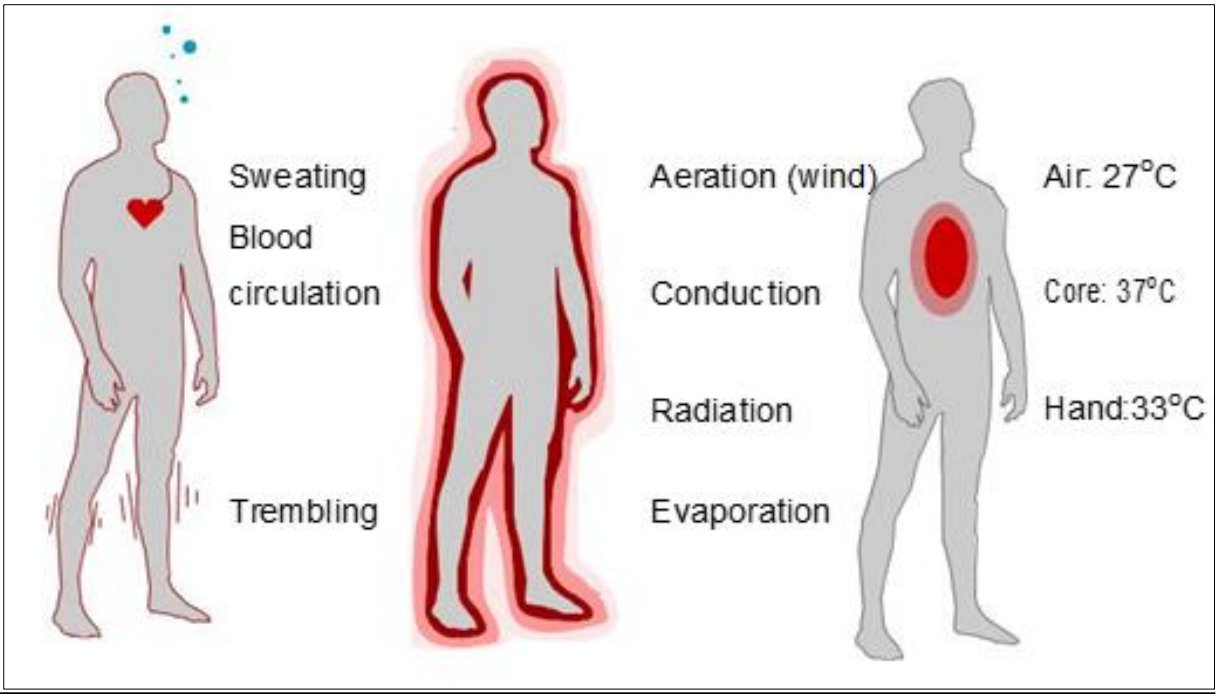


Figure 1. A simplified cold stress analysis methodology

The key purpose of the first stage is to understand the body heat balance concept, which is depicted in Figure 2. Understanding the effects of cold stress on the body, and how the body responds, can help to make life-saving decisions. The body, in general, attempts to maintain a constant core temperature (homeostasis) through a balance of heat loss and heat gain. For instance, body heat is normally gained by the application of external heat sources such as PPC/PPEs and, in normal situations through activities such as exercise and shivering. In general, body temperature is held nearly constant at 37°C at the heat production and heat dissipation are balanced accurately, under changing conditions, such as during work and rest as well as in cold and hot weather.



A) Temperature control B) Thermal output C) Favorable temperature

Figure 2. Body heat balance concept, modified from Norskoljeoggass (2012)

Body heat is lost in several ways, and there are four major mechanisms (Canadian Safe Boating Council, 2011):

- *Radiation*, which is a mechanism where the heat generated from within the body, is given-off to the surrounding atmosphere.
- *Evaporation*, is the second heat loss mechanism, and it occurs when you sweat or when your skin or clothing gets wet, the evaporation of that liquid (i.e., the change from liquid to vapor form) promotes heat loss, and the natural result is a cooling effect.
- *Convection:* is the third heat loss mechanism, where air or water flowing by the skin and, carrying away body heat. For instance, in case of cold-water contact, a heat loss via convection is the heat loss, which needs to be prevented by staying as still as possible in the water and, consequently the heated boundary layer remains undisturbed (OSHA, 2016). The reason behind staying still is that, if you move around in the water, you disrupt that boundary layer of warmer water, and that increases heat loss.
- *Conduction:* is the other heat loss mechanism, and it occurs due to temperature difference between the body and the operating environment. Normally, the body conducts heat to whatever the skin is in direct contact with. Conductive heat loss, in general, occurs when the skin is subjected to either cold air or water; however, it is especially critical in water, as body loses heat about 25 times faster in water than in air of the same temperature.

DIRECT & INDIRECT COLD-RELATED HEALTH AND SAFETY PROBLEMS

Several factors influence the cold injuries, such as negative air and sea temperature, icing, and their negative synergy effect on the human performance. The focal point of the second stage in

the proposed methodology is to investigate the direct and indirect cold-related hazards, which are mainly due to predominant factors. Table 1 depicts the main factors that increase danger from the cold. In order to work safely, challenges have to be counterbalanced by proper insulation (e.g. layered protective clothing), buddy system, physical activity, diet and nutrition, acclimatization, and controlled exposure to cold (work/rest schedule) (Jussila et al., 2010). For instance, to protect heat loss in cold water, dry and insulated clothing between the human body and the cold water is critical. This is very important, both to avoid the dangerous immediate cold shock, maintain muscle function, and maintain the body's core temperature. The inside lining is the most important part of the insulation of the rescue equipment. Moreover, it is vital to avoid insulated clothing from getting wet inside. If a liter of water gets inside of the insulated cloth, for instance, the insulation will be reduced by about 40% (Killian, 2012).

Table 1. Factors influence the cold injuries, modified from OSHA (2016)

Factor	Description
Air movement	High wind exposure, strong ventilation, moving through air - as in an open vehicle.
Humidity (wetness)	Water conducts heat away from the body 25x faster than dry air. Wet skin, clothing or shoes from being wet with water, gasoline, alcohol, solvent, or other liquid that evaporates.
Physical Activity	The production of body heat by physical activity (metabolic rate) is difficult to measure. In most case, Tables are used to show metabolic rates for a variety of activities. Metabolic heat production is in general measured in kilocalories (kcal) per hour. For instance, one kilocalorie is the amount of heat needed to raise the temperature of one kilogram of water by 1°C.
Work/rest schedule	For safe working environment in cold climate, The American Conference of Governmental Industrial Hygienists (ACGIH) has adopted work schedule as Threshold Limit Values (TLVs) for cold stress.
Protective clothing	For work at or below 4°C, adequate protective clothing is vital. Clothing should be selected to suit the temperature, weather conditions (e.g., wind speed, rain), the level and duration of activity, and job design. - *Under-dressing:* Exposed fingers, cheeks, nose, ears; uncovered head. - *Over-dressing:* Too-thick clothing rather than layers; tight-fitting belt, clothing or shoes that restrict circulation; waterproof clothing that restricts evaporation.
Medical conditions	Especially those affecting circulation, such as diabetes, an underactive thyroid, heart disease, history of frostbite.
Medications	Some medications such as tranquillizers and beta-blockers cause drowsiness or decrease vasoconstriction.
Alcohol, caffeine, nicotine	Alcohol impairs judgement and reduces shivering. Caffeine increases urine production and blood circulation; both lead to a loss of body heat. Nicotine decreases blood flow to the extremities and raises the risk of cold injury.

Direct cold-related health problems

Effective cold stress analysis requires managers to draw together the technical expertise to evaluate the cold-related hazards and, the risks these hazards pose to the workers. Further, effective safety decision-making involves selecting appropriate protective clothing and equipment for workers. As part of controlling cold risk efforts, it is essential to put in place a coordinated, multiagency plan for monitoring hazards, which arises due to cold exposure.

Hypothermia

Hypothermia is one of the most common direct cold-related health problems and, it is in general a drop in the body's internal temperature below 35°C and, it is a threat in frigid weather; it can also strike at moderate temperatures (Ward et al., 2012). In most of the cases, hypothermia is considered as a medical emergency with a high fatality rate and, Table 2 summarized the main conditions of hypothermia. In general, hypothermia can be generally categorized into five subcategories (Ward et al., 2012, Brown et al., 2012):

- *Acute immersion hypothermia:* this type of hypothermia in general occurs when a person falls into cold water.
- *Sub-acute exhaustion hypothermia:* can happen to any worker in a cold environment as well as to skiers, climbers and walkers in the mountains.
- *Accidental hypothermia:* this type of hypothermia is associated with significant morbidity and mortality and, it is due to a drop in core body temperature to <35°C (Brown et al., 2012).
- *Hypothermia in trauma:* a type of hypothermia, which disrupt virtually all major body systems, and is a risk for all trauma patients (Ruffolo, 2002).
- *Sub-clinical chronic hypothermia:* this type of hypothermia poses a serious challenge because the condition may negatively impact the plan of care for very old and frail patients (Campbell and Travis, 1997).

Table 2. Conditions of hypothermia, modified from Group (2013).

Mild Hypothermia	**Moderate Hypothermia**	**Severe Hypothermia**
- Core temperature 95°F (35°C) – 93.2°F (34°C) - Uncontrolled, intense shivering - Unable to solve problems - Mild depression, confusion - Loss of fine motor skills - Cool, pale skin - Coldness is creating some pain and discomfort - The 'umbles' – stumble, mumble, fumble	- Core temperature 91.4°F (33°C) – 87.8°F (31°C) - Uncontrolled shivering - Muscles begin to stiffen - Mental confusion and apathy sets in - Speech becomes slow, vague and slurred - Breathing becomes slower and shallow - Drowsiness and strange behaviour may occur - Shivering stops. Lethargic.	- Core temperature below 87.8°F (31°C) - Skin is cold, may be bluish-gray in colour - Eyes may be dilated - Muscle rigidity - Gradual loss of consciousness - No apparent breathing - Unconscious - May appear dead.

Frostbite

A frostbite is a condition caused by extreme cold exposure, in which your extremities such as fingers, toes, etc. freeze, so that they swell, become darker, and sometimes drop off (Killian, 2012). In most of cases, the feet, hands, ears, nose, cheeks, and penis are the most frequently injured sites (Jussila et al., 2010). In general, in case of frostbite condition, skin, muscle, blood vessels, and nerves freeze and form ice crystals and, blood vessels become blocked with tissue debris that causes more damage (OSHA, 2016). Frostbite is often irreversible and amputation is sometimes required. On the other hand, in the case, the injured site heals; the victim may suffer chronic pain or numbness, excessive sweating, abnormal skin color, and joint pain. There are some common sign and symptoms related to frostbite, such as: sensations of coldness, tingling, stinging, or aching sensation, skin feels numb and cold to the touch, skin is waxy and appears yellowish/white, and blistering, turning red, then black (Group, 2013).

Immersion foot/ Trench foot

Immersion or trench foot is the case when the body is covered with water or wet mud, which is just above freezing, the area may become chronically swollen, weak, and sensitive to the cold (Group, 2013). In general, trench foot is mainly due to prolonged exposure (12 hours or longer) of the feet to wet, cold conditions. It is very serious non-freezing cold injury and, occurs when cold exposure softens skin, causing tissue loss and, often, infection. If untreated, in most cases, can eventually require amputation (OSHA, 2016). Early signs for immersion foot case includes, itching, numbness, or tingling pain and, eventually swelling of feet. Trench foot is characterized by: yellowish, smelly feet, possible numb, and sloughing of skin tissue/itching (Group, 2013).

Chilblain and snow blindness

Chilblain, also known as pernio, are the painful inflammation of small blood vessels in your skin, which occurs in response to prolonged exposure to cold but not freezing air (Group, 2013). Redness, swollen skin, usually on hands and feet, that feels hot, tender to touch, and itchy after cold exposure are the most common symptoms and signs of chilblain (Ward et al., 2012). In general, the snow blindness symptoms occur within 8 to 12 hours of cold exposure; at first eyes feel dry and irritated, thereafter, it feels as if they are full of sand, moving or blinking becomes extremely painful, exposure to light hurts the eyes, eyelids may swell, eye redness, and excessive tearing (Group, 2013).

Indirect cold-related health problems

Cold exposure can also cause various types of indirect cold related hazards, in addition to the direct cold-related hazard and safety problems, these problems include (Ayele et al., 2015, OSHA, 2016, Killian, 2012, Mearns et al., 2003):

- *Disease flare-ups*: Conditions like arthritis and asthma can be made worse in cold environments.
- *Increase in injuries*: Cold weather can decrease dexterity, mental skills, coordination, and cause a general decline in performance that affects safety.
- *Strains and sprains*: Working in cold weather can increase the risk of injuries to muscles and tendons, for instance, back strain.
- *Other health effects*: Sinus irritation, viral infections, chronic lung disease, arthritis.
- *Increased ear and eye infection*s, which in turn can impair hearing and vision, which may increase the risk of accidents.
- Worsening of existing rheumatic conditions, and
- *Occurrence of Raynaud's Syndrome*, a vascular disease in which constricts blood vessels in the extremities such as the hands and feet, causing the blue coloring of the affected areas accompanied by on-going pain and discomfort and cold stress.

CONTROL MEASURES TO PREVENT COLD-RELATED INJURIES

The emphasis of the third stage in the proposed methodology is to evaluate control measures that can be employed to reduce the negative impacts of cold exposure. In addition, effective cold stress analysis involves understanding the available options or control measures and, how to choose among them. Analyzing control measure can help to determine what additional safety resources maybe needed when operating in cold environment. Control measures for reducing

cold exposure, in general, fall into four categories: engineering controls, administrative controls and work practices, personal protective clothing and equipment (PPC/PPE), and training.

Engineering controls

Engineering controls are one of the vital controls, which can be employed to reduce the impact of the cold-related injuries (Ayele et al., 2015). The first step in implementing engineering controls is reviewing equipment design. For instance, metal handles and bars should be covered by thermal insulating material and, unprotected metal chair seats should not be used. In addition, machines and tools should be designed so that they can be operated without having to remove mittens or gloves (Group, 2013). In addition, reducing the cold weather exposure of the work task through mechanical assistance (such as snow-blowers, etc.), is the other engineering control measure (Risikko et al., 2003). Moreover, providing warm areas for break, such as portable heating units, heated shelters, access to warm buildings, etc., and protecting the worker from drafts to the greatest extent where possible (e.g. shielding) are the other control measures (OSHA, 2016, Group, 2013).

Administrative controls & work practices

In most cases, implementing the administrative controls and work practices, will help to assess the demands of all jobs, have monitoring, and control strategies in place for cold days and cold workplaces (Killian, 2012). For instance, for outdoor workplaces, triggers for applying control strategies could include, wind chill (equivalent chill temperature), "Work Warm-Up Schedule", and environment weather reports (OSHA, 2016). In addition, it is also helpful to increase the frequency and length of rest breaks and, allowing a period of adjustment to the cold before assigning a full work schedule. Moreover, allowing workers to set their own pace, and take extra work breaks when needed and, educating new or newly transferred workers on the hazards of working in a cold environment is vital (Group, 2013). Further, carrying out as many tasks as possible indoors and reduce timeframe people must work outdoors and, working outside during the warmer hours of the day (mid-day/early afternoon) will reduced the negative impact of cold exposure (Group, 2013).

The other vital administrative measure, is training workers to recognize the signs and symptoms of cold stress and start a ''buddy system'' since people are not likely to notice their own symptoms (Jussila et al., 2010). This system will help take appropriate preventive steps, if symptoms arise in a co-worker. This is especially essential, for older workers, or those with certain medical problems, which need careful attention in regards to cold stress (Group, 2013). Where appropriate, developing an emergency response plan should be in place in the event of a cold related illness. Furthermore, keeping track of the temperature and air movement and, linking it to an action program is the other key administrative measure. For instance, for indoors activities, readings of temperature and air movement should be taken in all cold work areas at the start, middle, and end of each shift, at least every four hours (Group, 2013, Risikko et al., 2003). On the other hand, for outdoors activities, the weather report can be used. For instance, where there is air movement from wind, ventilation or travel in an open vehicle like a forklift, the wind chill index should be used to evaluate the hazard, instead of the air temperature (Jussila et al., 2010). The reason is that wind chill index takes into account the wind blowing the heat away from the body. In general, wind-chill effect is the perceived decrease in air temperature felt by the body on exposed skin due to the flow of cold air. The air temperature

combines with wind speed to describe the wind chill factor, which is the effect of these two parameters on exposed skin (Ayele et al., 2015).

Personal Protective Clothing and Equipment (PPC/PPE)

When working at or below 4°C personal protective clothing are essential, and Table 3 elucidates typical personal protective clothing. In general, selection of cold weather protection should be done in compliance with international and national standards, such as OSHA (US Occupational Safety & Health Administration) and, PEOSH (Public Employees Occupational Safety and Health) standards on personal protective equipment can be useful for selecting appropriate PPC/PPE. These are PEOSH 1910.132 for general requirements, PEOSH 1910.136 for foot protection and PEOSH 1910.138 for hand protection. Moreover, for the indoor environment based on air temperature and relative humidity in air, ISO 7720 and ASHRAE 55-2010 standards can be used. Furthermore, PPC/PPE must be properly selected to suit the temperature, weather conditions, duration of activity and job design:

- Multiple layers of clothing, inner layer to 'wick' moisture away from body to keep it dry (OSHA, 2016). Wear, in general, at least three layers: outer layer, which is windproof and that allows some ventilation; middle layer of wool, quilted fibers, or synthetic fleece to create an insulating layer; and, inner layer of synthetic fabric or wool to provide ventilation and allow moisture to escape (Group, 2013).
- Appropriate wool knit cap or a liner under a hard hat and appropriate gloves or mittens. In general, use gloves for work below 4°C for light work and below -7°C for moderate work; and, mittens for work below -17°C (Group, 2013). It is recommended that to wear mittens instead of un-insulated gloves, since mittens are warmer because your fingers stay together or use thermal insulated gloves and, nylon overmitts can be easily put on and taken off if gloved hands are necessary (OSHA, 2016, Group, 2013).
- Appropriate boots, such as felt-lined, rubber-bottomed, leather-topped boots with removable felt insoles for heavy work are necessary to reduce the trench foot hazard (OSHA, 2016). Further, when the work involves standing on the water, then waterproof boots are required. Moreover, boots with linings are preferred as they can be taken apart to dry more easily, or new linings can be used (Group, 2013).
- Eye and face protection, such as glasses/goggles, scarfs, to reduce the hazard from wind, blowing snow, glare, UV, etc. are vital(OSHA, 2016). In extremely cold conditions, eye protection must be separated from the nose and mouth to prevent exhaled moisture from fogging and frosting eye shields or glasses (Jussila et al., 2010, Group, 2013).

Training

Workers who are exposed to cold as part of their job and, their supervisors should take the health, safety, and environment (HSE) training course regarding working in cold environments. In general, the training should discuss various controlling measure for reducing cold exposure, such as engineering controls, work practices, and protective equipment to reduce the risk of cold stress. Moreover, supervisors and workers should be trained to watch for signs of cold stress and allow workers to interrupt work when uncomfortable as well as managing work schedules to allow rest periods (Group, 2013). Furthermore, supervisors and managers should also take the course on Job Safety Analysis (JSA). JSA generally, assists supervisors and managers in planning a job safely from beginning to end. In addition to formal training, supervisors can also take the opportunity to review: department procedures or work-specific

procedures for cold stress (or other health and safety requirements) in other forums such as toolbox talks, operations meetings, etc. (OSHA, 2016).

CONCLUSION

This work introduced a simplified methodology for cold stress analysis, by considering the effect of the extreme cold operational conditions. The proposed methodology consists of four main stages: *i*) understanding body heat balance concept (to recognize the temperature control process, body heat loss mechanisms, factors that increase danger from the cold), *ii*) evaluating cold-related hazards (to investigate the direct and indirect hazards and risks due to cold exposure), *iii*) analyzing control measures (to evaluate measures that can be employed to reduce the negative impact of cold exposure), and *iv*) establishing cold exposure monitoring programme (to review, explore, and reinforce control measures).

The proposed methodology is particularly important in the cold operating environment since it is easy to implement and, enforce a course of the proposed actions during a cold-related incident, which can prove to be highly useful. Further, enforcing the simplified steps can protect the health and safety of the workforce by managing the cold stress related issues. Our conclusion is that the use of a simplified cold stress analysis methodology has a vital role for ensuring that an organization do not accepts unnecessary risks, makes risk decisions in a way that guarantees safe operation during cold exposure, and manages risk by planning and, establishing cold exposure monitoring program.

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