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Report

Arctic weather protection, health effects, monitoring systems and risk assessment

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ABSTRACT
The growth in petroleum exploration and production in the Barents Sea and the Arctic region offers new challenges to health and safety. Factors that might influence safe and efficient operations due to the cold climate in the Arctic include both risks due to human error and risks to the physical and psychological well-being of individuals. The current NORSOK S-002 standard is weak on aspects relevant to cold protection in the Arctic.
As Statoil is looking for opportunities in the Arctic regions this literature study has reviewed the knowledge of risk factors related to cold ambient conditions, the effect of cold on physical and cognitive performance as well as cold-related injuries and health problems. Three Arctic clothing concepts have been tested by a thermal manikin to provide guidelines for recommended protection according to the IREQ model. The report provides recommendations and guidelines for working in Arctic conditions related to cold weather protection, exposure criteria's, health effects of cold exposure (including indication of critical requirements for vulnerable people), mitigation of work related injuries because of slides and falls, monitoring systems and cold risk management and assessment (including the wind chill index).

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SINTEF

1 Terms and definitions

acclimation
a physiological change, occurring within the lifetime of an organism, which reduces the strain caused by experimentally induced stressful changes in particular climatic factors

acclimatization
a physiological change, occurring within the lifetime of an organism, which reduces the strain caused by stressful changes in the natural climate

adaptation
a change which reduces the physiological strain produced by a stressful component of the total environment. This change may occur within the lifetime of an organism (phenotypic) or be the result of genetic selection in a species or a subspecies

ambient temperature
the average temperature of a gaseous or liquid environment (usually air or water) surrounding a body, as measured outside the thermal and hydrodynamic boundary layers that overlay the body

arrhythmia
an abnormal heart rhythm. In an arrhythmia the heartbeats may be too slow, too rapid, too irregular, or too early

atopic dermatitis
a form of eczema, is a non-contagious disorder characterized by chronically inflamed skin and sometimes intolerable itching

beta blockers
medicines that affect the body's response to certain nerve impulses. This, in turn, decreases the force and rate of the heart's contractions, which lowers blood pressure and reduces the heart's demand for oxygen

body heat balance
The steady-state relation in which heat production in the body equals heat loss to the environment

body heat content
the product of the body mass, its average specific heat, and the absolute mean body temperature

bradycardia
an abnormal slowness of the heart as evidenced by a slowing of the pulse rate

circadian
relating to the approximate 24-h periodicity of a free-running biological rhythm, or to the exact 24-h periodicity of an environmentally synchronized biological rhythm which persists with an approximate 24-h periodicity when not environmentally synchronized

clothing insulation
basic clothing insulation, that is the resistance of a uniform layer of insulation covering the entire body that has the same effect on sensible heat flow as the actual clothing under standardized (static, wind-still) conditions

cold stress
climatic conditions under which the body heat exchange is just equal to or too large for heat balance at the expense of significant and sometimes uncompensable physiological strain (heat debt)

conductive heat flow
heat flow by thermal conduction through the body surfaces in contact with solid objects

convective heat flow
heat exchange by convection between the boundary surface (clothing or skin) and the environment

core temperature
mean temperature of the thermal core of the body

chilblains
a dermatopathy due to cold, damp climates

congestive heart failure (CHF)
CHF is a condition in which the heart's function as a pump is inadequate to deliver oxygen rich blood to the body

coronary heart disease (CHD)
see ischemic heart disease

cryoglobulinemia
the presence in the blood of cryoglobulin, which is precipitated in the microvasculature on exposure to cold

dermatosis
any skin disease, especially one not characterized by inflammation

end-diastolic
occurring at the end of diastole, immediately before the next systole, as in end-diastolic pressure

erythema
redness of the skin due to congestion of the capillaries

habituation
reduction of responses to or perception of repeated stimulation

heart rate
number of heart beats observed per one minute time interval

heat loss
the rate of heat transfer from an organism to the environment, or from one part of an organism to another, by conduction, convection, radiation, evaporation, or a combination of these

heat stress
climatic conditions under which the body heat exchange is just equal to or too small for heat balance at the expense of significant and sometimes uncompensable physiological strain (heat storage)

hypothermia
is a condition in which core temperature drops below the required temperature for normal metabolism and body functions which is defined as 35.0 °C

hypertension
high blood pressure, defined as a repeatedly elevated blood pressure exceeding 140 over 90 mmHg - a systolic pressure above 140 with a diastolic pressure above 90

hypovolemia
diminished volume of circulating blood in the body

ischemic heart disease (IHD)
any of a group of acute or chronic cardiac disabilities resulting from insufficient supply of oxygenated blood to the heart

local skin temperature
skin temperature measured at a specific point of the body surface

mean body temperature
the sum of the products of the heat capacity and temperature of all the tissues of the body divided by the total heat capacity of the organism (mean body temperature can be estimated approximately from measurements of skin and core temperature)

mean skin temperature
sum of the products of the area of each regional surface element and its mean temperature divided by the total body surface area

metabolic rate
rate of transformation of chemical energy into heat and mechanical work by aerobic and anaerobic metabolic activities within an organism, usually expressed in terms of unit area of the total body surfaces

metabolism
the sum of the chemical changes in living matter in which energy is transformed

myocardial infarct
the term "myocardial infarction" focuses on the heart muscle, which is called the myocardium, and the changes that occur in it due to the sudden deprivation of circulating blood

neuroleptics
any of a class of drugs used to treat psychotic conditions

open work area
Area with no substantial obstacles to the open air and completely exposed to ambient conditions

oxygen consumption
rate at which the lungs take up oxygen

panniculitis
inflammation of the panniculus adiposus, especially of the abdomen

psoriasis
a chronic, non-contagious disease characterized by inflamed lesions covered with silvery-white scabs of dead skin

radiative heat flow
heat exchange by radiation between the boundary surface (clothing or skin) and the environment

recovery time
recovery period necessary to restore normal body heat balance after exposure (to severe cold environment)

rectal temperature
temperature measured by a transducer inserted in the rectum at least 100 mm past the edge of the anus

relative humidity
ratio (× 100) of the partial pressure of water vapour in the air to the water vapour-saturation pressure at the same temperature and the same total pressure

required clothing insulation
resultant clothing insulation required during the actual environmental conditions to maintain the body in a state of thermal equilibrium at acceptable levels of body and skin temperatures

resultant clothing insulation
factual insulation provided by a clothing ensemble under given environmental conditions and activities

sedative
medicine that has a calming effect and may be used to treat nervousness or restlessness

semi-open work area
Area that is weather-protected (e.g. with weather louvers) and partially exposed to the open air

thermal comfort
subjective satisfaction with the thermal environment

thermoneutral zone
temperature interval within which the body maintains heat balance exclusively by vasomotor reactions

urticaria
a vascular reaction of the upper dermis marked by transient appearance of slightly elevated patches (wheals) which are redder or paler than the surrounding skin and often attended by severe itching; the exciting cause may be certain foods or drugs, infection, or emotional stress

vasculitis
refers to a varied group of disorders which all share a common underlying problem of inflammation of a blood vessel or blood vessels. The inflammation may affect any size blood vessel, anywhere in the body. It may affect either arteries and/or veins

vasoconstriction
narrowing of the blood vessels that results from contraction of the muscular walls of the vessels. The opposite of vasoconstriction is vasodilation

wind chill temperature
temperature related to the cooling effect on a local skin segment

working environment
the totality of all physical, chemical, biological and psychological factors at work that may positively or negatively affect the employees' health and well-being.

work area:
a work area is an area of the facility where personnel stay or move in connection with work.

work place:
a work place is a volume within a work area, allocated to one or more persons to complete work tasks.

2 Symbols and abbreviated items

MBI	body mass index, $kg \cdot m^{-2}$
Clo	a unit to express the relative thermal insulation values of various clothing assemblies
CNS	central nervous system
COF	coefficient of friction
DLE	duration of limited exposure
HAV	Hand-arm vibration syndrome
I_{cl}	basic clothing insulation, $m^2 \cdot K \cdot W^{-1}$
IREQ	required clothing insulation, $m^2 \cdot K \cdot W^{-1}$
$IREQ_{min}$	minimal required clothing insulation, $m^2 \cdot K \cdot W^{-1}$
$IREQ_{neutral}$	neutral required clothing insulation, m^2 $K \cdot W^{-1}$
PPE	personal protective equipment
RP	Raynaud's phenomenon
WCT	wind chill temperature, °C
UTCI	Universal Thermal Climate Index
W	watt (1 J/s)
WCET	wind chill equivalent temperature, °C
WCI	wind chill index
HSE	Health Safety and Environment
ISO	International Organisation for Standardization
NORSOK	Norwegian offshore Petroleum Industry Standard
OGP	International Association of Oil and Gas Producers
OHS	Occupational Health and Safety
WG	Working Group

3 Normative References:

The following referenced standards are assessed and used as guidance for the recommendations in this document:

ISO 19900 Petroleum and natural gas industries - General requirements for offshore structures

ISO 19901-1, Petroleum and natural gas industries - Specific requirements for offshore structures- Part 1: Metocean design and operating considerations

ISO 19906, Petroleum and natural gas industries - Arctic offshore structures

ISO 9886:2004, Ergonomics-Evaluation of thermal strain by physiological measurements.

ISO-8996: 2004 Ergonomics - Determination of metabolic heat production.

ISO-9920:2008 Ergonomics of the thermal environment - Estimation of the thermal insulation and evaporative resistance of a clothing ensemble.

ISO 11079:2007 Ergonomics of the thermal environment. Determination and interpretation of cold stress when using required clothing insulation (IREQ) and local cooling effects.

ISO 12894:2001 Ergonomics of the thermal environment - Medical supervision of individuals exposed to extreme hot or cold environments.

ISO 13731:2001 Ergonomics of the thermal environment – Vocabulary and symbols.

ISO 13732:2005 Ergonomics of the thermal environment - Assessment of human responses to contact with surfaces. Part 3 - Cold surfaces.

ISO 15743:2008 Ergonomics of the thermal environment - Cold workplaces - Risk assessment and management.

ISO 15831:2003 Thermal manikin for measuring the resultant basic thermal insulation.

NS-EN ISO 20345:2004 Personal protective equipment. Safety footwear

NS-EN ISO 20345:2004/A1:2007 Personal protective equipment. Safety footwear

EN ISO 20344:2004 Personal protective equipment—test methods for footwear. Brussels, Belgium: European Committee for Standardization.

EN ISO 20345:2004 Personal protective equipment—safety footwear. Brussels, Belgium: European Committee for Standardization.

EN ISO 20346:2004 Personal protective equipment—protective footwear. Brussels, Belgium: European Committee for Standardization.

EN ISO 20347:2004 Personal protective equipment— occupational footwear. Brussels, Belgium: European Committee for Standardization.

EN 342:2004 Protective clothing **-** Ensembles and garments for protection against cold. European standards

EN 343:2003 Protective clothing - Protection against rain. European standards

EN 511:2005 Protective gloves against cold. European standards.

NORSOK STANDARD S-002:2004. Working environment.

4 Informative references:

OGP report no. 488. Performance indicators for fatigue risk management systems, Guidance document for the oil and gas industry (2012).

OGP report no. 343. Managing health for field operations in oil and gas activities (2011).

OGP report no. 398. Health aspects of work in extreme climates. A guide for oil and gas industry managers and supervisors (2008).

TR 0926, 2012-03-05. Working Environment. Health Safety and Environment. Technical and professional requirement. (Statoil Internal Document).

WEHRA. Working Environment Health Risk Assessment. 2010-02-01 (Statoil Internal Document).

DNV 2012: Barents 2020– stage 4. Assessment of International Standards for Safe Exploration, Production And Transportation Of Oil And Gas In The Barents Sea, Final Report Phase 4.

Lovdata: FOR 2010-12-20 nr 1780: Forskrift om helsekrav for personer i arbeid på innretninger i petroleumsvirksomheten til havs.

Norwegian Directorate of Health. IS-1879.2012. Guidelines to Regulations regarding health requirements for persons working on installations in petroleum activities offshore.

Helsedirektoratet. IS-1879. 2011. Veileder til Forskrift om helsekrav for arbeidstakere på petroleumsfeltet.

Web sites visited:

Environment Canada (http://www.ec.gc.ca/meteo-weather/default.asp?lang=En&n=5FBF816A-1#wc4)

Meteorologiske og oseanografiske parametre fra kyst-, hav- og landposisjoner, DNMI, http://www.regjeringen.no/pages/14137473/Vedlegg_12_6.pdf

GRID Arendal: http://www.grida.no/graphicslib/detail/definitions-of-the-arctic_12ba#).

http://dx.doi.org/10.1175/1520-0442(2003)016<2067:VATOAT>2.0.CO;2

Meteorologiske og oseanografiske parametre fra kyst-, hav- og landposisjoner, prepared by DNMI, http://www.regjeringen.no/pages/14137473/Vedlegg_12_6.pdf

http://www.metoffice.gov.uk/weather/marine/guide/beaufortscale.html

http://www.lovdata.no/for/sf/ho/xo-20101220-1780.html

http://www.helsedirektoratet.no/publikasjoner/veileder-til-forskrift-om-helsekrav-for-personer-i-arbeid-pa-innretninger-i-petroleumsvirksomheten-til-havs/Publikasjoner/veileder-til-forskrift-om-helsekrav-for-personer-i-arbeid-pa-innretninger-i-petroleumsvirksomheten-til-havs-engelsk.pdf

5 Summary

1. Technical recommendations

The classification of WCT risk categories in ISO 11079 should be used as basis guideline for cold stress. This report provides a modified version of risk categories in Table 6 (see chapter 15). ISO 11079 is more conservative (with regards to risk category 1 low risk of frostbite: -10 to -24 °C) compared to the new Environment Canada WCI (low risk of frostbite -10 °C to -27 ° C).
Risk of frostbite is influenced by a number of factors and the assumptions made in current WCI models still have some shortcomings. Based on the broad appliance of the WCI it is better to be on the safe side with regard to threshold values. We therefore consider the more conservative WCT threshold values for risk of frostbites given in ISO 11079 as the safest alternative. This recommendation is based on the following:

- Narrow regions of the body (finger and nose) will cool faster compared to the cheek – the current WCI models are based on cheek temperatures.
- Individual differences in time to skin freezing are not included in the current WCI models.
- The working environment can be influenced by local variations in wind, humidity and temperature that are not included in current WCI models.
- The risk in cold climate is not only related to frostbite. Deterioration in manual performance and thermal comfort occurs before there is a risk of frostbite.
- ISO 11079 has a well-established scientific and empirical foundation, and potential changes/improvements in risk classifications can be included over time.

To avoid the risk of frostbite, we recommend implementing a system of continuous environmental monitoring of all open and semi-open areas of the platform/installation where workers are expected to be exposed to WCT below -10 °C and the duration of outdoor activity is expected to exceed 40 minutes. These areas should be identified in the design stage of the planning and risk assessment of cold exposure.

2. Operational

Guideline for the use of WCT

Table 7 provides a guideline for recommended duration of outdoor exposure, risk of frostbite and preventive measures (clothing and protection, buddy system, physical activity) based on the wind chill temperature (WCT). This can be used as a general guideline; however it is recommended to use the IREQ model to get more exact information of required protection, duration of outdoor exposure and recovery times for each case. This should be done as part of a cold risk assessment.

Cold risk assessment and management

- It is recommended to use the occupational cold-risk assessment model provided in ISO 15743 as this includes both organizational and technical measures in work-place. This is in line with the recommendations from the Barents 2020 report (2012).
- It is further recommended that the cold risk model and practices presented in ISO 15743 should be integrated into the occupational health and safety management system of the company.
- The model should be adapted to the risk management models, rules and regulations currently in use by the petroleum industry.

Guideline for cold risk management:

- Establish a cold workplace team that should be responsible for the design and implementation stages and for continuous follow-up of cold-related issues.
- The management system should consider human factors such as experience, training, night-time operations (year-round in some cases), etc.
- For new operations, temporarily reduced performance should be considered, in the expectation that performance will improve.
- Achievement targets should be established and seasonal evaluations of performance should be carried out.

- A cold-risk management plan should be developed as a part of the general occupational safety plan of the individual workplace (this depends on the circumstances – offshore/land based etc.), the plan should at a minimum include:

  1. Cold-risk assessment checklist
     - Organizational cold protective measures
     - Duration and intensity of exposure
     - Time for recovery
     - Extra manpower
     - Planning of some activities to the summer
     - Monitoring system (buddy system/WCI)
  2. Technical preventive measures
     - Shelter
     - Tools and machinery
     - Reduction of slippery areas
     - Lighting
     - Insulation of work area
  3. Protective clothing and PPE
     - Need for thermal insulation (IREQ)
     - Clothing for cold and foul weather (EN 342)
     - Compatibility
     - Hand, foot, head, face protection
     - Information and training
     - Occupational health care

A detailed guideline for cold risk assessment and management is given in section 17.4

3. Health Exclusion Criteria

General recommendations

- The health requirements defined in "FOR 2010-12-20 nr 1780: Regulations relating to health requirements for people working on installations in offshore petroleum activities" with more detailed descriptions in "Guidelines to Regulations regarding health requirements for persons working on installations in petroleum activities offshore" should apply also for work in cold environments.
- Health exclusion criteria for work in the cold must be identified at individual level, after a thorough medical examination of the employee concerned.
- An occupational health care model for cold work should be implemented. Cold-related health assessment processes should be performed as outlined in ISO 15743 and ISO 12894 as suggested in RN05.
- The medical fitness examination for cold work should include information about:
- Cold-related symptoms and diseases (see section 18.8.1 – no. 5)
- anticipated physiological strain (work intensity, tasks)
- anticipated cold exposure and duration
- Knowledge about risk factors for hypothermia, frostbite, and nonfreezing cold injuries among workers and medical personnel

Specific recommendations are given in section18.8.2

6 Introduction

This report has been drawn up on behalf of Statoil Enquiry-021450 - Arctic weather protection, health effects, monitoring systems and risk assessment.

The growth in petroleum exploration and production in the Barents Sea and the Arctic region offers new challenges to health and safety. Workers in this hostile environment will be exposed to multiple stressors such as darkness, cold, snow and ice, remoteness, etc. that can lead to fatigue and impaired physical and cognitive performance (Russian – Norwegian expert group RN05, Barents 2020). Factors that might influence safe and efficient operations in the Arctic include both risks due to human error and risks to the physical and psychological well-being of individuals (Sandal et al 2009). The current NORSOK S-002 standard is weak on aspects relevant to the Arctic. The protective requirements as given in NORSOK S-002 mainly focus on frostbite protection. As Statoil is looking for opportunities in the Arctic regions these requirements need to be strengthened in order to offer workers better weather protection and to reduce other effects of cold exposure (both frostbite/wind chill, contact cooling and hypothermia). Temporarily shutting down a plant due to extreme weather conditions is expensive, which underlines the need for improved standards using the right criteria to select personnel or to abort operations. Statoil therefore need better knowledge of how ambient conditions affect physical and cognitive performance as well as of the prevalence of cold-related health problems.

7 Objectives

The main objectives of this study are:

- To improve the understanding of the need for better protection against the weather, negative effects on health, surveillance systems, and risk assessments for workers in the Arctic.

- To draw up guidelines for recommended use of the wind chill factor to help decide when to use weather protection, recommended work/reheat period and special protection equipment (PPE).

The project is divided into following sub-goals:

- Define the most relevant exposure criteria for weather protection, compared to mean annual values, as used today in NORSOK S-002.
- Define the protection needed for different types of work (inspection vs. operability and the possibility of coming into direct contact with cold metal).
- Suggest a risk assessment method for outdoor work in cold climate; determine when it should be used and what the minimum elements to be included are.
- Develop a proposal for a monitoring system for objective assessment of the outdoor thermal situation to reduce the subjective assessment. This should include conveniently adapted climate monitoring of critical work areas.
- Determine how we can incorporate the fact that different people react differently to cold stress (earlier frost injury, diabetes, etc.). Recommend health exclusion criteria.
- Propose a way to include mitigation of work-related injuries because of slides and falls related to snow and ice build-up and snowdrift on offshore installations.
- Define key elements as input to a procedure for how to work in cold climate

The report is divided into three sections. **Section I** provides a literature review of critical factors for work in cold climates. **Section II** provides the results and recommendations/guidelines for cold protection, exposure criteria, cold risk assessment, monitoring systems, health exclusion criteria and mitigation of slides and falls. **Section III** gives and overview of the key elements as input for a guideline for work in cold climates.

8 Deliverables

The main deliverables in the project:

- A summary of relevant research articles and documentation regarding critical factors for work in cold climate, updated information on wind chill indices/frostbite, contact cooling and hypothermia.

- Suggestions for new short requirement/standard/guideline for working in Arctic conditions related to weather protection, health effects of cold exposure (including indication of critical requirements for vulnerable people), surveillance systems and risk assessment (re. wind chill index).

Sub-deliverables

1. Definition of the most relevant exposure criteria for cold weather protection to be used as a more realistic tool than today's NORSOK S-002 (chapter 12).
2. Define the required protection related to the type of work (chapter 14 and 15)
    a. Insulation values (Clo) of existing clothing (three clothing concepts) used by petroleum workers.
    b. IREQ-analyses including climatic data and different working intensities based on work intensity and clothing used. Calculate allowable exposure time (duration limited exposure, DLE) and recovery times.
    c. Recommendations for adequate clothing for different work intensities, exposure times and cold related risks.
3. Risk assessment and management in the cold (chapter 16):
    a. Risk assessment for outdoor work in cold climate
    b. When risk assessment are to be used
    c. Minimum elements to be included in the risk assessment model
4. Suggestions for a monitoring system for objective assessment of the outdoor thermal situation in critical work areas (chapter 17).
5. Recommendations of health exclusion criteria for work in the cold (chapter 18).
6. Suggestions for mitigation of work related injuries caused by slides and fall related to snow and ice on the installation will be presented (chapter 19).
7. Define key elements as input to a procedure for how to work in cold climate (chapter 20).

9 Methods

The documentation in this project is based on biomedical articles published in international scientific journals. The articles have been identified by search, primarily in PubMed, but also in Science Direct and Springer Link databases between 1st March and 30th June 2013.In order to increase our knowledge of the topics defined in the sub-goals, our methods comprised literature studies and measurements of clothing insulation using a thermal manikin and calculation of the required thermal insulation using the IREQ model. This will form the basis for recommendations and guidelines for arctic weather protection, mitigation of negative health effects, monitoring system and cold risk assessment.

9.1 Organization

Contractor representative: Research Director Randi E. Reinertsen, Professor
Project manager: Research Manager Hilde Færevik, PhD
Project co-workers: Research Manager Mariann Sandsund, PhD, Øystein Wiggen, PhD, Julie Renberg, MSc
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She has a PhD in physiology from NTNU, Faculty of Natural Sciences and Technology, department of Biology. Hilde is working with problems related to human factors when exposed to extreme environments. She has been working at SINTEF as a researcher since 1998, and are currently Research Manager for a cross scientific group SmartWear (smart textiles and wearable electronics in clothing). She was the project manager of the ColdWear project (www.sintef.no/ColdWear/), and the coordinator to the EU project Safe@Sea (www.safeatsea-project.eu/) both aiming at developing new knowledge and solutions for protective clothing to increase health and safety of workers in extreme environments.

Project Co-workers:
Mariann Sandsund, PhD, Senior Scientist, Research Manager Work Physiology SINTEF
She has a PhD in physiology from NTNU and has been working at SINTEF as a researcher since 1993. Her currently position is Research Manager for the Work Physiology group at the department of Health Research. Her core competence is in cold physiology, physical activity and performance with focus on health promotion and disease prevention initiatives. She has been responsible for the part of the report concerning health criterias for cold work and slides and falls.

Øystein Wiggen, PhD, Researcher SINTEF
He has a PhD in physiology from NTNU, and a master degree from NTNU in exercise physiology. The PhD work focused on human performance and protective clothing for extreme and cold environment. He has been involved in this project in the laboratory work, including calculations of the WCI, the IREQ model and in the literature review.

Julie Renberg, MSc SINTEF
She has a master in physiology from NTNU where she studied the effect of ambient temperature on female endurance performance. She has been involved in this project including laboratory work and in the literature review.

Section I

Literature review

Critical factors for work in cold climate

10 Human responses to cold environments

Human beings are in principle tropical animals. Our internal body temperature range rarely exceeds 37 ±2 °C, even during exposure to extreme variations in environmental conditions. Greater deviations in deep-body temperature affect cellular structures, enzyme systems and a wide range of bodily temperature-dependent chemical reactions that affect health, safety and performance. With the use of clothing and shelter we have expanded our habitable areas to practically the entire world.

People who work and live in areas with an arctic climate are likely to frequently experience some form of cooling. Cooling is often related to survival situations in which hypothermia, defined as a core temperature lower than 35 °C becomes an important factor. Preventive measures and subjective evaluation hinder the development of hypothermia in most occupational settings in cold climates. However, even when a stable or elevated core temperature can be maintained, cold may still affect thermal comfort and performance (Drinkwater, 2008).

When the ambient temperature falls, the temperature difference between the skin and the environment is increased. This difference increases heat loss from the body to the environment. To reduce this initial heat loss, cutaneous blood flow is reduced by vasoconstriction. This mechanism reduces the temperature difference between the skin and the surroundings. Vasoconstriction is most pronounced in the extremities (Åstrand et al., 2003).

Human beings continuously strive to maintain body heat balance via various thermoregulatory mechanisms, in which heat balance is dependent on two factors; heat gain and heat loss. When heat production equals heat loss the human body is in heat balance. The primary heat-producing mechanism is the metabolic rate, which provides energy for the performance of mechanical work and maintenance of homeostasis. At rest, the metabolic rate is about 100W, and during periods of high-intensity work it can rise to about 1000W. The energy that is not transformed into mechanical work is dissipated via a number of heat-loss mechanisms. The most effective of these is through evaporation of water from the respiratory system and sweat. The other heat exchange mechanisms are convection, conduction and radiation.

The human body's ability to maintain thermal balance depends on the following parameters;

- **air temperature**
- **air velocity**
- **humidity**
- **radiant temperature**
- **metabolic heat production through physical activity**
- **clothing**

These six fundamental factors define the human thermal environment. However, internal thermoregulation only provides a short-term regulatory response, in which we eventually don or remove clothing or even seek shelter if the environmental conditions become too severe. This behavioural form of thermoregulation is the most important aspect of human thermoregulation.

The temperature-regulation system consists of four main components; 1) thermoreceptors, 2) neural pathways mediating afferent information from thermoreceptors and the central nervous system (CNS), 3) control unit located in the hypothalamus and 4) effector or efferent system (Parsons, 2010). Thermoreceptors are nerve endings located both in the skin surface and in deeper tissues which fire at different temperature range (Hensel, 1981). Even small deviations from the preferred temperature range or set point may reduce physical and mental performance. Effector mechanisms such as vasomotor activity (increased/decreased blood flow to the extremities), evaporative heat loss (sweating and respiration) or shivering are activated to prevent fluctuations in internal temperature and maintain heat balance. Sweat glands, skin blood vessels and skeletal muscles serve as effector organs.

11 Critical factors for work in cold climates

11.1 Cold exposure

Cold exposure can have various adverse consequences for human performance and health. At its mildest, cooling causes unpleasant sensations and thermal discomfort. Discomfort is a distraction factor, reducing the performance of tasks that require concentration and vigilance, and it may thus increase the risk of accidents and injuries both in occupational and leisure-time activities (Makinen, 2007). Tissue cooling diminish physical (Oksa, 2002) and mental performance (Palinkas, 2001), and extra effort is therefore be needed to complete a task compared performance in a warm environment. Reduced performance can increase the risk of accidents and injuries. Cold exposure is a triggering factor for certain diseases and may aggravate the symptoms of prevailing chronic diseases. The effects of cold are related to several factors, including the severity of the exposure (climate), physical activity, clothing, and individual and socioeconomic factors (Figure 1).

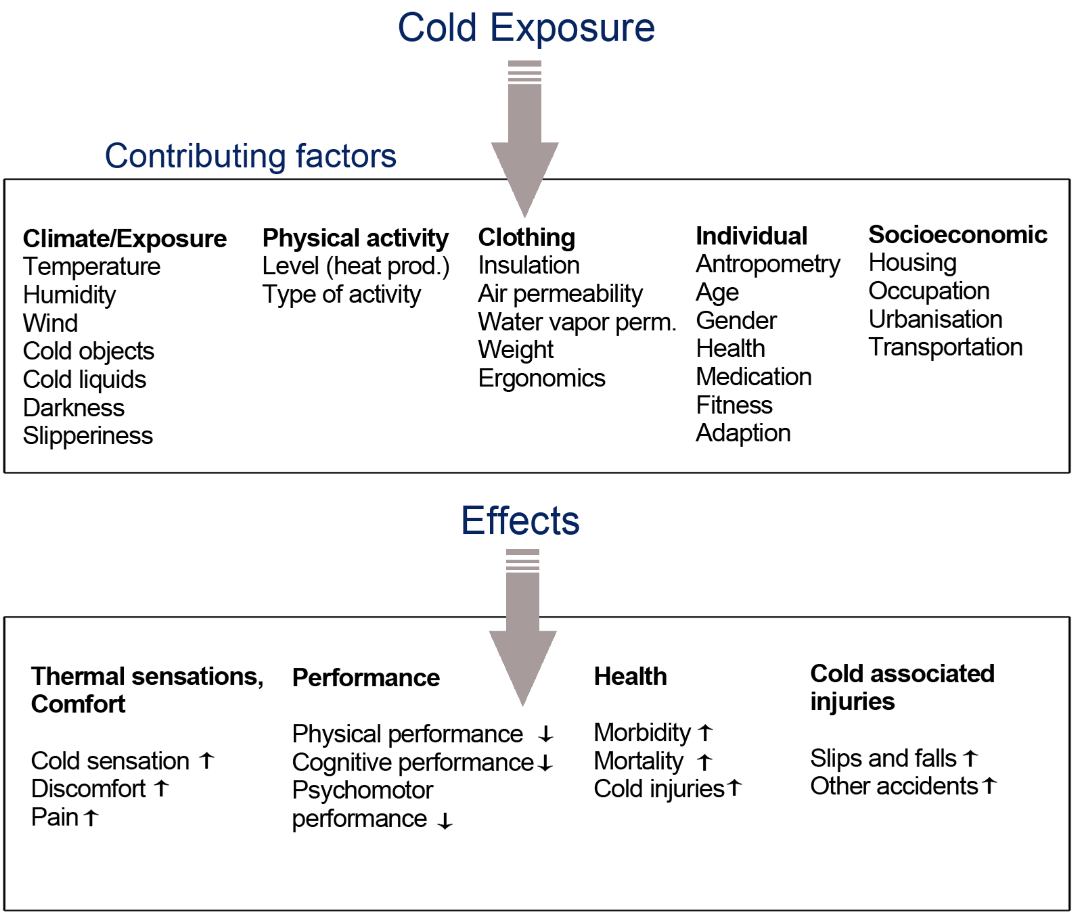

Figure 1 The effects of cold (adopted from Mäkinen et al (2007).

11.2 Individual factors

In addition to the six fundamental factors that define the human thermal environment, a number of individual factors determine the level of cold stress. The following sections offer a brief review of individual factors and of how these might affect the human body in the cold.

11.2.1 Age and temperature regulation in the cold

There is epidemiological evidence of increased mortality among older adults due to hypo- and hyperthermia (Kenney and Munce, 2003). This has led to the impression that elderly people are more susceptible to harm caused by extreme cold environments. However, this outcome does not entirely reflect an inability to thermoregulate with advanced age. Changes in thermoregulation in the elderly include changes in sweating, cardiovascular function, reduced peripheral vasoconstriction and metabolic heat production. However, studies that have attempted to separate the effects of chronological age from concurrent factors, such as fitness level, body composition, and the effects of chronic disease, have shown that thermal tolerance appears to be minimally compromised by age (Kenney and Munce, 2003). In a study, healthy older subjects (average 71 years old) were compared to healthy younger subjects (average 23 years old), and were matched for body composition (DeGroot and Kenney, 2007). They found no differences in skin temperature, but did find lower metabolic heat production and that the older subjects failed to maintain core temperature. They did not identify the underlying mechanisms for this reduction in core temperature. The reduced capacity to maintain core temperature in older subjects means that this group is more susceptible to hypothermia.

11.2.2 Gender and temperature regulation in the cold

Women feel cooler in a cool environment than men (Parsons, 2002), feel uncomfortable with the ambient temperature more often than men, and prefer a higher ambient temperature (Karjalainen, 2007). In eumenorrheic women, the core temperature varies by 0.3 °C to 0.5 °C during the menstrual cycle. When exposed to cold, women have lower mean skin temperature than men (Stevens et al., 1987), and this difference is also seen during exercise (Sandsund et al., 2011, Walsh and Graham, 1986), but these gender differences are not found in peripheral sites such as the fingers, toes and nose (Graham, 1988). A study has showed a significantly reduced sensitivity of the shivering response, relative to changes in rectal temperature, during the luteal and follicular phases of the menstrual cycle (Grucza et al., 1999). During the luteal phase of the menstrual cycle, women have a higher core temperature threshold for the initiation of the thermoregulatory response during cold stress (Stephenson and Kolka, 1993). It appears that men respond to cold stress by increasing their metabolic rate instead of allowing their skin temperatures to cool to the same extent as women do(Graham, 1988). Another gender difference in the response is a cardiovascular shift seen in men, but not in women, during cold stress (Stevens et al., 1987). Differences in height, weight and body composition between the genders (Graham, 1988) can lead to differences in heat exchange. Differences in muscle mass, percentage of body fat and fat distribution can lead to differences in the rate of heat exchange. Morphological differences may be part of the reason for the differences between the genders in thermoregulatory, metabolic and cardiovascular responses to cold stress, although the overall explanation is still unknown (Graham, 1988, Kaciuba-Uscilko and Grucza, 2001, Stocks et al., 2004).

The main factors potentially differentiating thermal responses in men and women are:

- Anthropometric characteristics, such as body mass and size
- Body composition, particularly muscle and body fat content
- Gender of physiological properties (sex hormones, body water regulation, exercise capacity)
- Social behavior (e.g. daily physical activity)

11.2.3 Fitness and temperature regulation in the cold

Good physical fitness is known to be one the most important factors for good health, and has also been shown to have several advantages for individuals who are exposed to a cold environment. A high level of fitness is characterized by elevated maximal oxygen consumption, allowing for more intense physical work and more prolonged work activity (Bittel et al., 1988). Higher work intensity results in higher heat production, and the level of cold tolerance is likely to increase. Fit persons are also likely to have greater thermoregulatory system sensitivity. The increased sensitivity, for instance shown by a higher skin temperature at the onset of shivering, would lead to more efficient thermoregulatory abilities against cold stress (Bittel et al., 1988). A high level of sensitivity to changes in the environment brings early responses and thus a reduced risk of profound cooling.

11.3 Thermal comfort

Thermal comfort is defined as “that state of mind which expresses satisfaction with the thermal environment” (Parsons, 2003). The condition of thermal comfort is therefore sometimes defined as a state in which there is no driving impulse to correct the environment by behavioral activity. Thermal comfort is dependent upon both environmental and individual factors and is influenced by the core and skin temperatures of the body (Fanger, 1970). The importance of thermal comfort (or discomfort) in working situations has been comprehensively investigated, since its effects on human health, performance and productivity are well-known (McIntyre, 1980). A feeling of discomfort in the cold can lower morale and even lead to a refusal to work (Parsons, 2003).There has therefore been active interest in research that defines conditions of thermal comfort. Four essential conditions are prerequisites for a person to be in thermal comfort; 1) the body is in heat balance; 2) sweat production is within comfort limits; 3) mean skin temperature is within comfort limits; 4) local discomfort is absent (e.g. cold hands/face/feet). Preferred ambient conditions for thermal comfort appear to be the same across geographical locations (warm/cold climates), age and gender (Parsons, 2003). Outside this narrow comfort zone, the sensation of cold and warmth is affected by e.g. age, gender, and body composition and acclimation state.

11.4 Hypothermia

Hypothermia is defined as a condition in which the deep body temperature falls below 35 °C. It usually occurs accidentally, and is not likely to be an issue when working in moderately cold environments. In extremely cold environments, without proper clothing and with a low level of activity, the body may not be able maintain heat balance and the deep core temperature will fall. The most severe situation is when people are immersed to cold water, which has a thermal conductivity about 25 times as great as air. Hypothermia is generally divided into three distinct types according to the degree of body cooling; mild (body temperature of 34-35 °C), moderate (body temperature of 30-34 °C) and deep hypothermia (body temperature < 30 °C) (Færevik, 2000). Mild hypothermia is characterized by changes in peripheral resistance due to vasoconstriction, thermogenic shivering and tachycardia (Lexow, 1989). Shivering is normally intense at 35 °C, and it causes a three- to five-fold increase in heat production. The victim is usually conscious and responsive. Peripheral vasoconstriction leads to an increase in central blood volume, which in turn induces diuresis (Ganong, 1997). At moderate hypothermia shivering gradually decreases and heat production declines. The victim’s consciousness is clouded and there is increased muscular rigidity with the result that muscular co-ordination is impaired (Bristow, 1984). The cold affects the myocardial conduction system`, inducing gradual cardiac slowing. Below 32 °C cardiac arrhythmia develops and ventricular fibrillation may occur if the heart is irritated (Bristow, 1984). There is a gradual fall in blood pressure because of bradycardia and a fall in peripheral vascular resistance. Deep hypothermia is a life-threatening condition. The victim is usually comatose, the skin is pale and the pupils are dilated and unresponsive to light. There is pronounced bradycardia and at 18-20 °C the heart usually stops. Respiration and pulse are difficult to register below 20 °C deep body temperature, and it is impossible to measure blood pressure. However, due to a decrease in the metabolic rate, the oxygen requirements of the brain are greatly lowered, which implies that hypothermia actually offers some protection against hypoxia.

11.5 Clothing and personal protection

Clothing and personal protection is a fundamental factor in most occupations involving some form of potential harmful exposure. Noise, chemicals and environmental (heat, cold, wind and rain) are all examples of such exposures. Clothing is in particular important when working in cold conditions, and should always be selected to suit the temperature, weather conditions, duration of exposure, activity level and type of work (Holmer, 1992). All these factors are important in order to avoid excessive sweating or cooling, which would increase risk of cold related injuries. In general, clothing should be worn in multiple layers. The inner layer should insulate and transport moisture away from the skin. The middle layer should primarily act as insulation, but also favor moisture transport. The outer layer should provide protection from the environments (wind and rain) and allow for easy regulation of heat and moisture transport. Sufficient protection of hands, feet and head is often the most challenging as the extremities are likely the first to suffer from cooling. Cooling of the extremities can lead to severe alterations in comfort and manual performance (Wiggen et al., 2011). Proper headgear must include protection of head, eyes and ears. It is important that the different parts of the headgear are compatible, such that no compromises occurs (i.e. hearing protection and thermal protection).We should continuously strive to optimize glove and shoe design. Improving workers' skill and awareness of how to dress and function for optimal performance under arctic environments will have beneficial effects. Providing a total protective clothing concept combined with instructions and better knowledge of how to protect oneself against harsh environmental conditions will make work possible under a wider range of extreme conditions without compromising safety, comfort and performance.

11.6 Experience and cold work

People working in cold environments face many risks (Holmer, 2009). Despite rules, regulations and guidelines it is finally the workers themselves who have to perform and maintain their functions to do the work properly. People working in a cold climate also often live in the same area. Over time they will gain experience and skills in keeping warm and comfortable under various environmental conditions. The degree of experience can be a challenging factor in the petroleum industry. Specialists and contractors are often hired in from all over the world. Persons from warmer climates may lack experience of cold-weather work. This can lead to over- or underdressing, profound sweating and reduced awareness concerning wind chill and contact with cold surfaces (Donaldson et al., 2001). It is not obvious to everybody that they should use a layer of woolen underwear next to the skin, multiple layers for easy adjustment of insulation and avoid overheating. Furthermore, new and "smarter" protective clothing can be more challenging to use correctly (Gore-Tex etc). Experience is thus a critical factor for work in the cold, and proper training and education about preventive measures should be provided. In general, workers in the cold must always remember to be prepared and be aware of current environmental conditions.

11.7 Adaptation/acclimatization to cold climates

Adaptation refers to the changes that reduce the physiological strain produced by stressful components of the total environment. In human beings, most of these adaptions occur within our lifetime (phenotypic), and in fact most thermal changes related to repeated cold exposure occur within a couple of weeks (Makinen, 2007), which suggests that potential cold adaptations can occur within a work shift. Nowadays, most cold adaptation is behavioral, including seeking shelter, using protective clothing, improving housing and transportation. It has been shown that northern Europeans tend to protect their extremities more efficiently than residents of Southern Europe for any given fall in temperature (Donaldson et al., 2001). In general, the modern lifestyle in regions with an Arctic climate indicates a lack of typical cold habituation responses (Makinen et al., 2004). The lack of adaptation can be explained by the use of adequate protective clothing, generally short periods of continuous cold exposure and high indoor temperatures (Makinen, 2007). However, we can assume that the physiological cold acclimatization profile is probably different among people employed in outdoor occupations and repeatedly exposed too cold for longer periods (Makinen, 2007).

11.8 Nutrition and water intake in cold climates

Compared to temperate conditions, total energy expenditure tends to be higher in cold conditions. The most likely reason for the increase in energy expenditure in the cold is the extra weight of the clothing and shoes, and the hobbling (restrictive and friction-producing) effects of heavy cold-weather, multi-layered clothing (Tharion et al., 2005). Shivering also increases energy requirements (Holtzclaw, 1993). Carbohydrate metabolism and lipid oxidation are enhanced in the cold. Carbohydrates are used as fuel for both shivering and exercise in the cold (Shephard, 1992, Vallerand and Jacobs, 2008). Increased lipid metabolism in the cold is primarily fueled by fatty acids released from depot fat (Vallerand and Jacobs, 2008). For this reason, workers in a cold climate require a higher caloric intake than for similar efforts in a temperate climate. Meals should be well balanced and one should eat suitably and frequently. Dehydration can occur during physical work and / or exposure to climate extremes. This means that dehydration can take place under both warm and cold conditions. Factors contributing to dehydration in the cold are cold-induced diuresis, respiratory water loss, cold-weather clothing, the metabolic cost of movement, and reduced fluid intake (Freund and Sawka, 1996). Adequate fluid intake is essential to prevent dehydration. People should drink fluids often, especially when doing hard work. The intake of caffeinated drinks such as coffee should be minimized, because this increases urine production and contributes to dehydration. Caffeine also increases blood flow to the skin, thus increasing heat loss. For heating purposes hot beverages or warm soup should be drunk.

11.9 Shift work in cold climates

Ozaki et al. (2001) claim that there is an increased risk of reduced manual performance on night shifts compared to day shifts in the cold. The study suggests that there is an increased risk of both hypothermia and accidents for those who work in the cold at night than during the day. Accidents and mistakes made by workers on the night shift have been the cause of several catastrophic events in our recent history (Mitler et al., 1988). A review article that evaluated the risk of incidents (accidents and injuries) on the morning, afternoon and night shifts on an 8 h shift system found an increased risk during the afternoon shift compared to the morning shift and an increased risk at the night shift compared to the afternoon shift (Folkard and Tucker, 2003). Working at an ambient temperature below -5 °C reduces manual performance during low work intensity while wearing standard protective clothing for the petroleum industry (Wiggen et al., 2011). Impaired manual performance was observed already at finger skin temperatures below 20 °C (Wiggen et al., 2011). Ozaki et al. suggest that body temperature is an important factor in manual performance; they observed a lower body temperature but higher finger temperature, at night. Core temperature varies during the day because of the circadian rhythm and this variation has been reported to influence human performance (Wright et al., 2002). A slight increase in body temperature, independent of the circadian rhythm, is associated with improved performance and alertness (Wright et al., 2002). Physical exercise at night has been shown to improve reaction time and response time, which can be explained by the exercise-induced increase in rectal temperature (Hansen, 2012). While some studies have demonstrated an increase in incident risk at night and others show a correlation between core temperature and performance, to the best of our knowledge, only one study has looked at manual performance during night shift work in the cold (Ozaki et al., 2001). A limitation of this study was the lack of a control group to compare performance during night shift work in the cold and the same work at night in a neutral ambient temperature. The question of whether working in the cold at night adds to the known risks of working the night shift still remains unanswered. Based on the known effect of circadian rhythms and lowered core and finger skin temperature on performance, and the increased risk of incidents during the night shift, further research is recommended to evaluate whether extra precautions should be taken when working outside in the cold at night.

11.10 Sleep and cold climates

Sleep difficulties have been reported by people in both the Arctic and Antarctic (Kennaway and Van Dorp, 1991, Angus et al., 1979). These problems can mostly be attributed to disruption of circadian rhythms in summer and winter, cold exposure, and psychosocial stress (Palinkas and Suedfeld, 2008). Extreme conditions may lead to sleep disturbances and sleep deprivation, which may limit cognitive and psychomotor performance" (Buguet, 2007). Human sleep is sensitive to small changes in the environment. Although many studies have examined thermoregulatory responses during sleep in the Arctic cold, few have evaluated objective measures of sleep in this environment. Cold exposure produces more disturbances in sleep cycles than warm exposure (Libert and Bach, 2005). Cold exposure increases restlessness during sleep and affects mainly REM sleep (Buguet, 2007). Acclimatization to cold takes weeks to develop, but some evidence suggests that pre-acclimation to cold may prevent the occurrence of sleep changes. Although not much work has been done on this matter, there does appear to be a signal for the importance of room temperature in combination with appropriate bedding insulation for optimal sleep. Other important factors that influence sleep are daylight variations (Paterson, 1975) and daytime activity (Buguet, 2007).

11.11 Ethnicity and temperature regulation in the cold

Different climatic zones around the world are inhabited by people who have adapted their lifestyle to accommodate the environmental conditions under which they live. Groups living under different conditions show physiological and morphological adaptations to their environment; birth weight, body shape and composition, cranial morphology and skin color and sensitivity (Lambert et al., 2008). When subjected to cold stress Caucasians and Eskimos show a higher shivering response, and therefore higher mean skin temperatures and rectal temperatures, than African Americans (Adams and Covino, 1958, Farnell et al., 2008). Australian Aborigines living traditionally maintain their body temperature by conserving heat, while unadapted Caucasians have a stronger shivering response to acute cold stress (Taylor, 2006). The Aborigines conserve heat by allowing skin temperatures and rectal temperature to fall without shivering. This habituated metabolic reaction can be induced in cold-adapted Caucasians (Taylor, 2006).

12 Performance in the cold

12.1 Cognitive performance

Human responses to cold are also influenced by psychological factors. Mental tasks may be adversely affected by cold exposure, while the expectations of people exposed to cold also play an important role. If not properly adapted/prepared to harsh/cold climate (clothing, shelter, training, etc.), exposure may quickly be perceived as a major threat if people are aware that they will be exposed to such a climate for many hours (Parsons, 2003). Expectations may influence their satisfaction with the thermal environment, and this is again influenced by their psychological characteristics, experience and culture. Cognitive performance plays a fundamental role in safety and decision-making, particularly in avoiding critical situations. Moderate cold exposure affects cognitive performance negatively through the mechanisms of distraction, and both positively and negatively through the mechanisms of arousal caused by the cold exposure (Mäkinen, 2006). When exposed to cold, an initial improvement in arousal is often observed before it results in a performance decrement (Mäkinen, 2006). An underlying causative model explaining the interaction between thermal environment and cognitive performance has not been developed, while physiological responses have been well described (Hancock et al., 2007).Work-safety standards that provide threshold values for performance in cold environments are therefore largely based upon physiological parameters. The basis of these theories is that the ambient temperature at which an individual can perform adequately is very close to the threshold temperature at which the body temperature can compensate physiologically for thermal strain (Hancock et al., 2007). Better knowledge of interactions between physiological parameters and cognitive responses is necessary for a better understanding of the critical temperature limits for safe performance.

12.2 Manual performance

In the petroleum industry many tasks depend on optimal manual performance, ranging from heavy lifting and tool handling to assembly of nuts and bolts, all of which require various types of fine and gross dexterity in combination with grip strength. It has been demonstrated that with the protective clothing currently used in the petroleum industry we can expect to see a reduction in manual performance at ambient temperatures of -5 °C or lower (Wiggen et al., 2011). Reduced manual performance increases the risk of errors, and given the potential devastating effect on environment and health from errors in the petroleum industry, this needs to be avoided by all possible means. The decrease in manual performance in the cold depends on a number of physiological factors. Local skin temperature and body heat content have been shown to be good indicators of alterations in manual performance (Brajkovic et al., 2001, Brajkovic and Ducharme, 2003). A local skin temperature of 15 °C has been suggested as a critical value below which manual performance deteriorates severely (Havenith et al., 1995). Furthermore, at skin temperatures of 8 °C or below, reduced manual performance can be related to neural factors. At skin temperatures of 6 °C a nervous blockade occurs, and at skin temperatures of 6-8 °C, we can expect loss of sensitivity and a decrement in manual performance (Heus et al., 1995). Direct or indirect heating of hands and fingers appears to be crucial for optimal manual performance during outdoor work in cold environments. A combination of functional work and warm-up routines, improved protective clothing and individual skill and knowledge on how to dress and operate in extreme environments will lead to improved safety, comfort, performance under a wide range of environmental conditions.

12.3 Physical performance

Physical performance constitutes of endurance, muscular fitness and physical skills. Cold and cooling of the body is likely to impair all of these parameters. Muscle cooling impairs most of its functional properties like power, force and velocity (Oksa, 2002). It has been demonstrated that cooling impairs both short (Wiggen et al., 2013) and long (Sandsund et al., 2012) term endurance. Although maximal endurance performance is not that relevant in occupational settings, other endurance variables like work economy will be impaired at reduced skin- and muscle temperatures (Beelen and Sargeant, 1991, Pendergast, 1988). A reduction in work economy increases the cost of movement that will lead to earlier fatigue for the workers. Once fatigue occurs the workers reduce their work intensity and the rate of heat production falls, which further reduces their ability to maintain thermal balance. In most occupational setting postural control is important in many daily activities, and especially during periods with freezing temperatures with icy and slippery surfaces. Cooling can affect postural control through a variety of mechanisms. Firstly, changes in mechanoreseptors in the sole and ankle and also proprioceptors located in the muscles, tendons and joints can change the sensory functions for postural control (Makinen, 2007). Secondly, cooling can also alter the reflex function in muscle spindles and neuromuscular function (Oksa, 2002). Thirdly, the nerve signal velocity can be slowed in both the afferent (norsk: tilførende) and efferent (norsk: som fører bort fra) nervous system, which can further lead to more difficulties in maintaining balance. The combined effect of increased cost of movement and reduced postural control during periods of rest increases the risk for mistakes in the course of a typical work day, and points out the importance of reducing the cold stress to a minimum.

12.4 Psychosocial factors and performance in cold climates

Psychosocial factors can affect feelings and moods of the worker, which in turn can affect performance (Paulus et al., 2009). Factors that contribute to behavioral health problems (such as homesickness, fatigue, temporary anxiety, sleep problems and mood disturbances) are amount of daylight, feelings of isolation and confinement, low temperature, organization of work and noise (Sandal et al., 2009). Individual resilience to these factors differ on the basis of such factors as age, sex, place of residence, ethnicity, occupation and personality (Sandal et al., 2009). Environmental factors, in combination with the amount of time that workers have to stay together, increase the probability of interpersonal problems. Managers have a powerful influence the motivation, well-being and safety behavior of their workers (Sandal et al., 2009). Another factor that influences the well-being and mental health of workers is shift-work, and in particular night work (Sandal et al., 2009).

Cold injuries and cold-related diseases are described in chapter 18.

SECTION II

Recommendations and guidelines

13 Cold exposure criteria

Objective:
Definition of the most relevant exposure criteria for weather protection to be used as a more realistic tool than NORSOK S-002.

13.1 Definition of the Arctic and its sub-areas

Several definitions of the Arctic as a region exist. The geographic boundaries of the Arctic vary, depending on the use; e.g July isotherm below 10ºC, vegetation distribution (tundra) or political boundaries (GRID Arendal: http://www.grida.no/graphicslib/detail/definitions-of-the-arctic_12ba#). A strict definition of the Arctic is the region above the Arctic Circle, an imaginary line that circles the globe at 66° 32" N. Illustration of the Arctic (Figure 2):

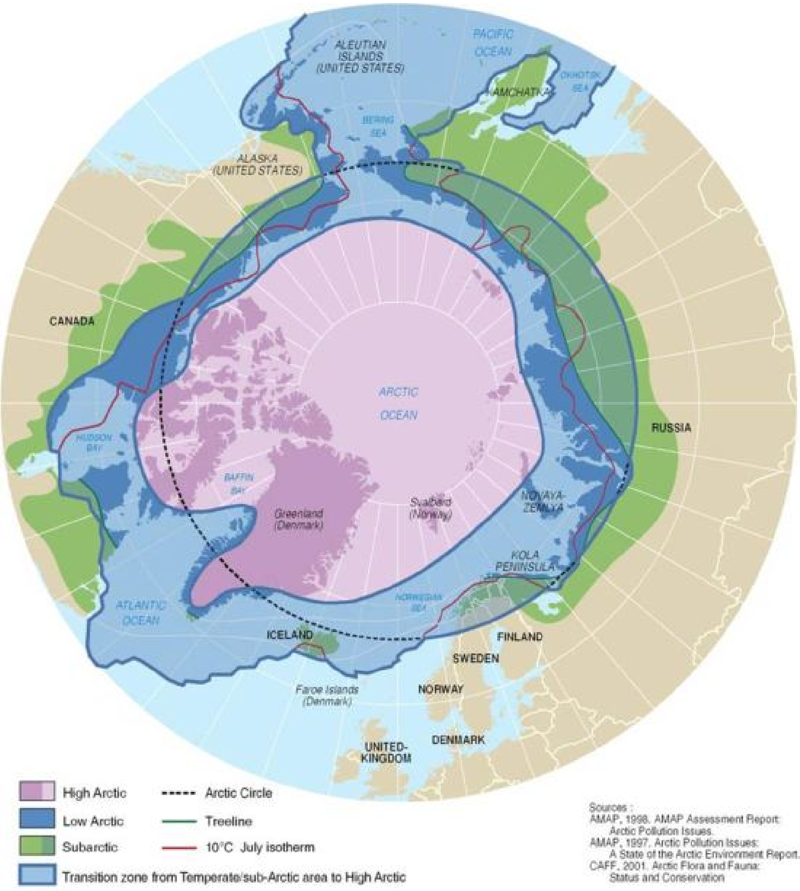

Figure 2 The Arctic. Cartographer/designer: Philippe Rekacewicz, UNEP/GRID-Arendal.

The Arctic and Antarctic Research Institute (AARI) of St. Petersburg has defined climatic zones of the Artcic into eight sub-areas of highly different climatic and ice-conditions: I. Spitsbergen, II. Norwegian, III. Franz Josef Land, IV. NE Barents Sea, V. Novozemelsky, VI. Kola VII. Pechora, VIII. White Sea. Sub-area II is generally ice free.Sub-areas I, III, IV, VII and VIII usually have ice every winter. Sub-areas V and VI are in-between. These sub-areas represent different climatic conditions and may provide a basis for risk assessment in the cold.

13.2 Climatic data for the Arctic

Numerous sources of climatic data can be found for the geographical areas of defined as the Arctic:

- Meteorologiske og oseanografiske parametre fra kyst-, hav- og landposisjoner, prepared by DNMI, http://www.regjeringen.no/pages/14137473/Vedlegg_12_6.pdf
- http://www.metoffice.gov.uk/weather/marine/guide/beaufortscale.html
- Gunnar Noer and Trond Lien, 2010, Dates and Positions of Polar lows over the Nordic Seas between 2000 and 2010, Norwegian Meteorological Institute, Report no. 16/2010(Noer and Lien, 2010)
- Meteocean Design Parameters for the Goliat Field. Saipem Energy Services/ ENI Norge (191 pages) wind/waves/water temp/air temp/climatic extremes
- Polyakov, Igor V., Roman V. Bekryaev, Genrikh V. Alekseev, Uma S. Bhatt, Roger L. Colony, Mark A. Johnson, Alexander P. Maskshtas, David Walsh, 2003: Variability and Trends in Air Temperature and Pressure in the Maritime Arctic, 1875–2000. J. Climate, 16, 2067–2077 http://dx.doi.org/10.1175/1520-0442(2003)016<2067:VATOAT>2.0.CO;2

Institutions providing information/databases on Arctic climatic data:

- Arctic and Antarctic Research Institute (AARI)
- National Snow and Ice Data Center (NSIDC)
- National Aeronautics and Space Administration (NASA)
- National Climatic Data Center (NCDC) database
- Norwegian Meterological Instititute (DNMI)

Information about regional meteorological conditions can be found in Annex B.16 of ISO 19906. According to Table B16-2 in ISO 19906, there are wide variations in meteorological conditions between the different regions of the Barents Sea. The Northeastern region of the Barents Sea has the most extreme values of low air temperatures (-39 °C) (with reference to table B16-2, ISO 19906). The area opened for the Norwegian petroleum industry corresponds to the western region described in ISO 19906. This area has an all-year winter climate. Average annual values for this area are a minimum temperature of -7.7 °C, maximum temperature of 4.4 °C and average annual wind speed of 26.6 m/sec measured 10 m above sea level.

Saipem Energy Services collected weather data, which are described in the report “Meteocean design parameters: Goliat field” (Goliat Development Project, 2010 Saipem Energy Services). Weather data from the Meteorological Office were used as references. Fruholmen Meteorological station (latitude: 71.093 N/ longitude: 23.995 E) is often used as the meteorological station representing the temperature and wind on the Goliat field area. However, if applied to Goliat field area, the Fruholmen extreme temperatures are conservative (Saipem Energy Services, 2010). Air temperature showed that the mean yearly temperature was 3.4 °C, with mean minimum and maximum temperatures ranging from 1.6 to 5.4 °C. Absolute maximum and minimum were 22.2 and -12.6 °C. The number of 24-hour periods with temperatures below 0 °C was 130. Mean wind speed was 16.4 m/s (11.0-21.4) with extreme values of 32.3 m/s (Saipem Energy Services, 2010).

Iden et al (Iden KA, 2012) studied meteorological data from the southeastern Barents Sea between 1958 and 2011. They concluded that there are large annual variations in maximum temperature and wind speed at the different locations investigated (corresponding to Statfjord A, Heidrun og Goliat). In this report the maximum temperature at Goliat is 15.6 °C, the minimum is -12.8 °C and the maximum wind speed is 28.0 m/s.

Noer and Lien (Noer and Lien, 2010) analysed meteorological data for the past 30 years in the Arctic. The report provides meteorological data as annual means for the whole period and seasonal distribution (January, February and March being the three coldest months). Average wind speed at

Fruholmen Fyr for the three coldest months was 16.08±6.29 m/s (10 m above ground level, data since 1993). The average for the summer months was about 4.9 m/s lower. Wind speeds above 20 m/s were registered 16.28% of the time. In comparison, Ekofisk had an average wind speed of 13.65±5.23 m/s and air temperature of 6.76±1.79 °C (measured 2 m above sea surface) in the three winter months. Wind speeds above 20 m/s were observed 6.52% of the time.

Polar lows

The Arctic area are characterised by cold fronts (polar lows) which is described as a weather system that forms in the Arctic and may move south to bring cold temperatures, strong winds and sea-spray that may cause icing of superstructures and equipment. Wind speeds may be as high as 28,4 m/s and last for 6-48 hours (www.met.no). Polar lows occur from October to May, most frequently in January to March. Thirteen polar lows were observed from 2000-2012 according to data from the Norwegian Meteorological Institute (Iden KA, 2012).

Icing

Icing is a serious threat for installations, particularly during sea sprays and winter storms. The Melkøya LNG plant, outside Hammerfest in Norway has reported a number of technical problems due to low temperatures and heavy icing, with more than 5 cm of accumulated ice thickness.

Climate change factors

The Norwegian Polar Institute expects that temperature in the Barents Sea area will rise by 2-4°C; that the frequency of strong winds and polar lows will decrease, precipitation will increase but the season of snow will become shorter (Førland and Benestad, 2009). The trend is towards more ice-free areas and access to new regions of the Arctic.

13.3 Recommendations for relevant exposure criteria for weather protection

There are wide variations in environmental variables in the climatic zones of the Artic. We recommend that Met-Ocean data (wind, air temperature, visibility, precipitation, and snow and ice conditions) are assessed at the geographical location of the installation or where an operation will be performed. The following recommendation for cold exposure criteria's:

- The environmental parameters should be monitored and forecast during the design phase according to ISO 19906:2010 and ISO 19901-1. Met Ocean data should be used as the basis for winterization design.
- Meteorological data should be specified as annual means for the past five years.
- Wind chill simulations should be performed for the seasonal variations for a whole year in order to define the important climatic data as the background for relevant exposure.
- The three coldest months of the year (usually January, February, March) should be used for making further estimates of the protection required in extreme situations rather than the annual mean as is used in NORSOK- S-002.
- WCT estimates should be made both for the extreme (maximum) and mean values of combinations of temperature and wind.
- The wind chill temperature (WCT) should then be calculated as described in the equitation in ISO/TR 11079, Annex D.
- Design consideration (shelter, clothing, personal protective equipment) should be drawn up on the basis of the estimated number of days defined as cold risk based on the risk of frostbite

With reference to chapter 15: *see Table 5 Classification of risk categories, wind chill temperature, risk of frostbite and recommended limits for work (modified from ISO 11079: 2007) and Table 6 Wind chill index: Cooling of bare skin in a combination of wind and temperature (ISO 11079:2007), and other functional requirements identified in the cold risk assessment analysis (see Figure 13 ISO 15743 Cold risk assessment – three-stage model.*

14 The wind chill index

Objective:
The objective of this task was to make a summary of relevant research articles and documentation about the wind chill index (WCI) and to give recommendation on the use of WCI.

14.1 Thermal indices

The human thermal environment encompasses both heat exchange between the body and the environment (stress) and the body's physiological response (strain) (Jendritzky et al., 2012b). A number of indices have been developed to assess the effects of climatic conditions on the human body. Comprehensive reviews of thermal indices can be found in Fanger (1970), Parsons (2003) Landsberg (1972) Driscoll (1992) and Jendritzky et al. (2012a). Thermal stress indices can be divided into rational, empirical and direct indices:

Rational indices
Rational thermal indices often use heat transfer equations and/or mathematical models of the human thermoregulatory system to predict the human response to the thermal environment. The IREQ model for cold stress is based on heat transfer equations and can be useful as a cold stress index (ISO11079:2007). The IREQ model is based on heat balance equations, and when using this model one should be aware heat balance alone is not sufficient for thermal comfort.

Empirical
Empirical indices are derived from samples of human subjects who are exposed to a range of thermal conditions.

Direct indices
The goal of a direct index is to make a model that estimates the human response to the thermal environment (strain) as a single parameter. It provides a simple, practical method of allowing effective design, construction and evaluation of the human thermal environment. However, it must be regarded as a simple thermal index as it does not take into account all the factors that influence the human response to the thermal environment.

The original WCI is a direct index that combines the effect of ambient temperature (T_a) with the air speed (v) to estimate the cooling power (heat loss from the body to the environment) expressed as wind chill temperature (WCT) (ASHRAE, 1997, ASHRAE, 2005). It is one of the most widely used cold indices in the world and provides a practical method of providing safety limits for work in cold climate. Since the original work on the WCI by Siple and Passel (1945), a number of studies have attempted to improve the index (Osczevski, 1995, Tikuisis and Osczevski, 2002, Osczevski and Bluestein, 2005, Bluestein and Zecher, 1999, Tikuisis, 2004, Shitzer and de Dear, 2006). The WCI was used until 2001 by the national weather services in North America as a common winter weather predictor. In 2001 the National Weather Service in the USA and Canada replaced the old WCI charts with the new Wind Chill Temperature (WCT). The WCT values in the new WCI charts are considerably higher (warmer) at wind speeds higher than 2 m/s than those predicted by the old charts. Estimates of the risk of frostbite under various conditions were added to the wind chill charts by Tikuisis and Osczevski (2002).

Definition of the new Wind Chill Temperature (WCT)
The wind chill temperature (WCT) is a calculated air temperature that, in the absence of wind, would result in the same skin surface heat loss to the environment as in the actual windy environment (Osczevski and Bluestein, 2005). A target skin temperature of -4.8°C is used for a 5% risk of frostbite in the WCI (Danielsson, 1996)

14.2 Wind chill indexes – NORSOK S-002, ISO 11079 and Environment Canada

14.2.1 NORSOK S-002 versus ISO 11079

ISO 11079 and NORSOK S-002 present WCI in two different ways. ISO 11079 presents WCI as a wind chill temperature and NORSOK S-002 as W·m^{-2}. The NORSOK standard refers to ISO 11079, and some readers may find it hard to understand and interpret the values presented in NORSOK S-002. The heat loss per square meter is more often used in engineering terminology, and is more suitable for use in the early planning phases for work in cold environments. However, WCT is a simplification that seems to be easier to understand and will be more applicable for end-users, such as persons in charge of HSE and those working out on installations. Figure 3 presents ISO 11079 and NORSOK S-002 with their respective values and threshold values. Wind speed is defined as the standard meteorological value measured 10 m above ground level. If the local wind velocity is measured, it must be multiplied by 1.5 before it is inserted in the formula presented in ISO 11079 Annex D.

Wind scale	Wind speed		Ambient temperature (°C)										
Beaufort (m·s^{-1})	Km·h^{-1}	m·s^{-1}	0	-5	-10	-15	-20	-25	-30	-35	-40	-45	-50
Light breeze (1.6-3.3)	5	1.4	-2 / 798	-7 / 919	-13 / 1040	-19 / 1161	-24 / 1282	-30 / 1403	-36 / 1523	-41 / 1644	-47 / 1765	-53 / 1886	-58 / 2007
	10	2.8	-3 / 932	-9 / 1073	-15 / 1214	-21 / 1355	-27 / 1496	-33 / 1638	-39 / 1779	-45 / 1920	-51 / 2061	-57 / 2202	-63 / 2343
Gentle breeze (3.4-5.4)	15	4.2	-4 / 1022	-11 / 1177	-17 / 1332	-23 / 1486	-29 / 1641	-35 / 1796	-41 / 1951	-48 / 2106	-54 / 2261	-60 / 2415	-66 / 2570
	20	5.6	-5 / 1090	-12 / 1255	-18 / 1420	-24 / 1585	-31 / 1750	-37 / 1915	-43 / 2080	-49 / 2245	-56 / 2410	-62 / 2575	-68 / 2741
Moderate breeze (5.5-7.9)	25	6.9	-6 / 1143	-12 / 1316	-19 / 1489	-25 / 1662	-32 / 1836	-38 / 2009	-45 / 2182	-51 / 2355	-57 / 2528	-64 / 2702	-70 / 2875
	30	8.3	-7 / 1186	-13 / 1366	-20 / 1545	-26 / 1725	-33 / 1905	-39 / 2085	-46 / 2264	-52 / 2444	-59 / 2624	-65 / 2803	-72 / 2983
Fresh breeze (8.0-10.7)	35	9.7	-7 / 1221	-14 / 1407	-20 / 1592	-27 / 1777	-33 / 1962	-40 / 2147	-47 / 2332	-53 / 2517	-60 / 2702	-66 / 2887	-73 / 3072
	40	11.1	-7 / 1251	-14 / 1440	-21 / 1630	-27 / 1819	-34 / 2009	-41 / 2198	-48 / 2388	-54/ 2577	-61 / 2767	-68 / 2956	-74 / 3146
Strong breeze (10.8-13.8)	45	12.5	-8 / 1275	-15 / 1468	-21 / 1661	-28 / 1854	-35 / 2048	-42 / 2241	-48 / 2434	-55 / 2627	-62 / 2820	-69 / 3013	-75 / 3207
	50	13.9	-8 / 1295	-15 / 1491	-22 / 1687	-29 / 1884	-35 / 2080	-42 / 2276	-49 / 2472	-56 / 2668	-63 / 2865	-70 / 3061	-76 / 3257
Near gale (13.9-17.1)	55	15.3	-9 / 1311	-15 / 1510	-22 / 1709	-29 / 1908	-36 / 2106	-43 / 2305	-50 / 2504	-57 / 2702	-63 / 2901	-70 / 3100	-77 / 3298
	60	16.7	-9 / 1325	-16 / 1526	-23 / 1726	-30 / 1927	-37 / 2128	-43 / 2328	-50 / 2529	-57 / 2730	-64 / 2931	-71 / 3131	-78 / 3332
	65	18.1	-9 / 1335	-16 / 1538	-23 / 1740	-30 / 1942	-37 / 2145	-44 / 2347	-51 / 2549	-58 / 2752	-65 / 2954	-72 / 3157	-79 / 3359
Gale to hurricane (> 17.2)	70	19.4	-9 / 1344	-16 / 1547	-23 / 1751	-30 / 1954	-37 / 2158	-44 / 2362	-51 / 2565	-59 / 2769	-66 / 2972	-73 / 3176	-80 / 3380
	75	20.8	-10 / 1350	-17 / 1554	-24 / 1759	-31 / 1963	-38 / 2168	-45 / 2372	-52 / 2577	-59 / 2781	-66 / 2986	-73 / 3190	-80 / 3395
	80	22.2	-10 / 1354	-17 / 1559	-24 / 1764	-31 / 1969	-38 / 2174	-45 / 2380	-52 / 2585	-60 / 2790	-67 / 2995	-74 / 3200	-81 / 3405

Figure 3 Cooling power of wind on exposed flesh expressed as a wind chill temperature (WCT according to ISO 11079 annex D) and heat loss per square meter (W·m^{-2} according to NORSOK S-002). It is shown as WCT / W·m^{-2}. The background color is according to risk classification defined by ISO 11079 (Table 1) and the red and blue markings are according to the risk classification in NORSOK S-002 (Table 2).

NORSOK and ISO 11079 utilize different criteria associated with the evaluation of the risk of cold injury and/or allowable duration of exposure (Table 1 and Table 2). The threshold values utilized by NORSOK S-002 can be regarded more conservative than those of ISO 11079, especially with regard to the effect of wind chill. However, NORSOK S002 allows for a lower ambient temperature under windless conditions. The NORSOK S-002 recommend 1600 W·m^{-2} as the absolute threshold value, in which no outdoor work should be performed. According to Parson (2003) the 1600 W·m^{-2} value represents a wind chill temperature where exposed flesh freezes within an hour. In Annex D, Table D.2 ISO 11079 presents different categories of risk of skin freezing. According to ISO 11079 risk classification3 and 4, exposed skin may freeze within 10 and 2 minutes, respectively. Continuous wind chill exposure between 2 and 10 minutes is likely to occur during a work shift, however 60 minutes of continuous wind exposure rarely happens. NORSOK S-002 refers to the equation for estimation of WCT in ISO 11079, even though there are different threshold values between the two standards.

Table 1 Wind chill temperature and freezing time of exposed skin (ISO 11079 Annex D)

Classification of risk	Wind chill temperature (°C)	Effect
1	-10 to -24	Uncomfortably cold
2	-25 to -34	Very cold, risk of skin freezing
3	-35 to -59	Bitterly cold, exposed skin may freeze in 10 min
4	-60 and colder	Extremely cold, exposed skin may freeze within 2 min

Table 2 Operational restrictions to prevent harmful effects of wind chill on unprotected skin (NORSOK S002 – chapter 5.8)

Wind chill index ($W{\cdot}m^{-2}$)	Effect
> 1 600	No outdoor work to be performed
1 600 > WCI > 1 500	The available working time per hour and person increases from 0 % to 33 % linearly
1 500 > WCI > 1 000	The available working time per hour and person increases from 33 % to 100 % linearly

14.2.2 Environment Canada

Environment Canada (http://www.ec.gc.ca/meteo-weather/default.asp?lang=En&n=5FBF816A-1#wc4) presents another set of risk classifications. ISO 11079 and Environment Canada refer to the same equation for the calculation of WCT. The differences in risk classifications are not large, but can make the decision on absolute threshold values more complex. As an example, the absolute lowest allowable WCT; according to ISO 11079 is WCT of -35°C (high risk of frostbite) and for Environment Canada -40°C (high risk of frostbite). Another example of complexity is when you calculate wind chill as $W{\cdot}m^{-2}$ [a] a threshold value of 2048 $W{\cdot}m^{-2}$ is estimated at an ambient temperature of -20°C and wind speed of 45 $km{\cdot}t^{-1}$ when using ISO 11079, while a threshold value of 2174 $W{\cdot}m^{-2}$ is estimated at an ambient temperature of -20°C and wind speed of 80 $km{\cdot}t^{-1}$ when using the Environment Canada WCI.

14.3 Risk and time to frostbite during exposure to cold and wind

Knowing the risk and the time it will take to develop frostbite are both useful in helping people decide what to wear in the cold and in providing a framework for management of cold work (Ducharme and Brajkovic, 2005). A number of studies have calculated the effect of the wind chill on the risk and time to develop frostbite by using a thermal cylinder. Only a few studies exists that have actually studied the risk of frostbite using human subjects (Danielsson, 1996, Ducharme and Brajkovic, 2005). The WCT threshold values for risk associated with cooling of exposed skin are still a matter of debate.

Risk of frostbite is dependent on several factors:

- Temperatur and wind
- Duration of exposure
- Individual factors
- Regions of skin cooling (nose, cheek, finger)

The critical skin temperature in the WCT calculations used in the ISO 11079 is -4.8°C for a 5% risk of frostbite (Danielsson, 1996). Danielsson (1996) demonstrated that as the skin surface temperature falls from -4.8 to -7.8°C, the risk of frostbite increases from 5 to 95%. The risk of finger frostbite is minor above an air temperature of -10°C, irrespective of wind, but below -25°C there is a pronounced risk, even at low wind conditions (Danielsson, 1996). Osczevski calculated that a -4.8°C skin temperature is reached at a WCT of -27°C under steady state conditions using convective heat loss measurements from a cylinder (Osczevski and Bluestein, 2005). Ducharme and Brajkovic (2005) studied the risk and the time required to develop frostnip on the face over a wide range of environmental conditions (0°C to -50°C, 0 to 9 m/s wind) on 12 human subjects. 52 cases of frostnip were observed, 73% on the nose, while 15%, 8% and 4% were observed on the chin, cheek, and forehead, respectively. While both the Canadian and the ISO 11079 WCI is based on estimations of cooling rate on the cheek, eight times faster cooling rate is estimated for the more narrow regions of the body (finger and nose) (Schitzer and Tikuisis 2012). The faster freezing onset of thin, narrow exposed regions of the body compared to thicker, wider regions reflect differences in the size and shape of various exposed body parts (Shitzer and Tikuisis, 2012). The time factor is highly important when estimating the risk of frostbite. Ducharme and Brajokovic (2005) demonstrated that the time to develop frostnip decreased from 20 min at -20°C and 32 km/h wind to 1.5 min at -40°C and 32 km/h wind. Ducharme and Brajokovic concluded that a WCT of -27°C and warmer represents a low risk of frostbite for most people. However, the cooling rate of the exposed skin also depends on individual factors such as age, body composition and body heat content, and these estimates are not included in the current WCI.

Shitzer and Tikuisis (2012) conclusions about the WCI:

- Prediction of times to skin freezing (in essence, safe exposure limits) would be more meaningful and easier to interpret than the WCT
- Cooling time would also enable direct measures of degraded function (e.g loss of finger dexterity) under moderate conditions and the risk of cold injury (e.g frostbite under more serious conditions to be included
- Bare skin will cool faster under higher wind conditions (asymmetrical cooling) – the current WCI is based on steady state cooling.
- Narrow regions of the body (finger and nose) will cool faster compared to the cheek – the current WCI is based on cheek temperatures.

14.4 Advances and shortcomings of the new wind chill index

Shitzer and Tikuisis (2012) describes the recent advances, and the shortcomings of the new wind chill charts adopted by the US and Canada in 2001. They recommend a number of refinements, including the use of whole body models in the computation, and verification of heat exchange. Some of their main points are summarized in the following:

Advances in the new WCI:

- Estimation of frostbite risk under different conditions (based on a time-dependent model of facial cooling, (Tikuisis and Osczevski, 2002))
- Adjustment of meteorologically reported wind speed measured 10m above the ground to reflect the value blowing at face level (1.5 m above ground level).
- Redefinition of "calm wind conditions" to 1.34 m/s (set to reflect the movement of cold air relative to the body generated simply by walking under completely "still" wind conditions).
- Numerical model to calculate skin surface temperature changes derived from human experiments which makes the WCET calculation procedure more scientifically sound.
- Corrections of inconsistency in the model.
- Replacement of the constant "comfort skin temperature" of 33°C with values calculated by the numerical model.
- Inclusion of inner body temperature constant of 38°C in the numerical model.

Shortcomings of the new WCI:

- Convective heat exchange coefficients in the model used in the calculations were not based on human experimental data but regressed from experimental data using a cylindrical object representing the human head in forced convection.
- Convective heat exchange coefficients defined were evaluated at 50°angle relative to the front of the face, representing the average cheek value. A more severe choice would be to assume direct frontal wind at 0° angle, representing a "worst case scenario".
- The convective heat exchange coefficients are highly dependent on wind speed and to a lesser extent on air temperature.
- The contribution of environmental and solar radiation in human heat exchange is not included. Although the contribution of radiation is smaller than that of wind-driven convection (ranges from 8 to 23%), it should be estimated when establishing overall heat exchange with the environment.
- Whole-body effects are not included. Heat exchange with the environment is influenced by physical activity and clothing. High activity level and high clothing insulation raise core and skin temperature, which in turn modify heat loss to the environment.
- The calm wind condition used in the model does not necessarily reflect the facial heat loss threshold values that directly influence the WCT values. The calm conditions employed should be justified through specifically designed human experiments.
- The assumption of steady state conditions made in the model can be questioned. At what point should wind-chill effects be evaluated?
- Blood perfusion effects should be factored into the calculations to quantify how this modifies the thermal resistance of the cheek during vasoconstriction.

Further work required:

- Application of a whole-body thermoregulation model, e.g., Fiala's model (Fiala et al., 2001), which forms the basis for the recently presented UTCI (2009), to evaluate exposed facial temperatures. This would facilitate the inclusion of activity levels, clothing worn, inner body temperature variations, the sequential occurrences of potential frostbites at different exposed body sites, etc., and would thus bring the predictions closer to realistic values than the one-dimensional models in current use.
- The use of experimental human data to evaluate environmental heat exchange coefficients. The coefficients employed at present are invariably based on expressions derived from non-human

experiments. Alternatively, these expressions should at least be validated against limited human experimental data collected in cold winds, in order to establish existing differences.
- Reconsideration of the calm wind condition in order to reflect real facial heat loss threshold values in cold and windy environments.
- Specific integration of environmental (not solar) radiation effects in the computational procedure.
- Quantification of the dependence of the heat exchange coefficients not only on wind speed but also on air temperatures.
- Reevaluation of the probability of risk of frostbite and consideration of pain and numbness thresholds

14.5 The Universal Thermal Climate Index (UTCI)

The growing need for assessment of the outdoor thermal environment in climate impact safety research and planning led to the notion of developing a Universal Thermal Climate Index based on the most recent scientific progress in thermophysiology and heat-exchange theory (Brode et al., 2013). A number of advanced heat budget models have been developed since the 1960's in attempts to include all the factors that form the human thermal environment. In spite of all the effort put into developing more advanced comprehensive models for assessment of the thermal environment, none of them have been accepted as a fundamental standard (Jendritzky et al., 2012a). Therefore a COST Action 730 (a European programme promoting Cooperation in Science and Technology) was established to create the essential synergies between multidisciplinary experts in the field of thermal physiology, mathematical modeling, occupational medicine and meteorological data-processing to develop the UTCI index (http://www.utci.org). The operational procedure and UTCI calculation is available as software from the UTCI website. The process of developing a UTCI addressed the following issues:

- Physiological modeling of the human body and its heat budget
- Physiologically relevant assessment of heat budget model outcomes, including acclimatization
- Testing results against available field data
- Identification and pre-processing of meteorological input data
- Estimating radiation quantities/levels
- Addressing the specific needs of individual applications.

The UTCI model provides comprehensive heat budget models which take all significant heat exchange mechanisms into account. The ability of the UTCI to adequately predict the human physiological response to a variety of moderate and extreme conditions is represented in the COST 730 database (Figure 4).

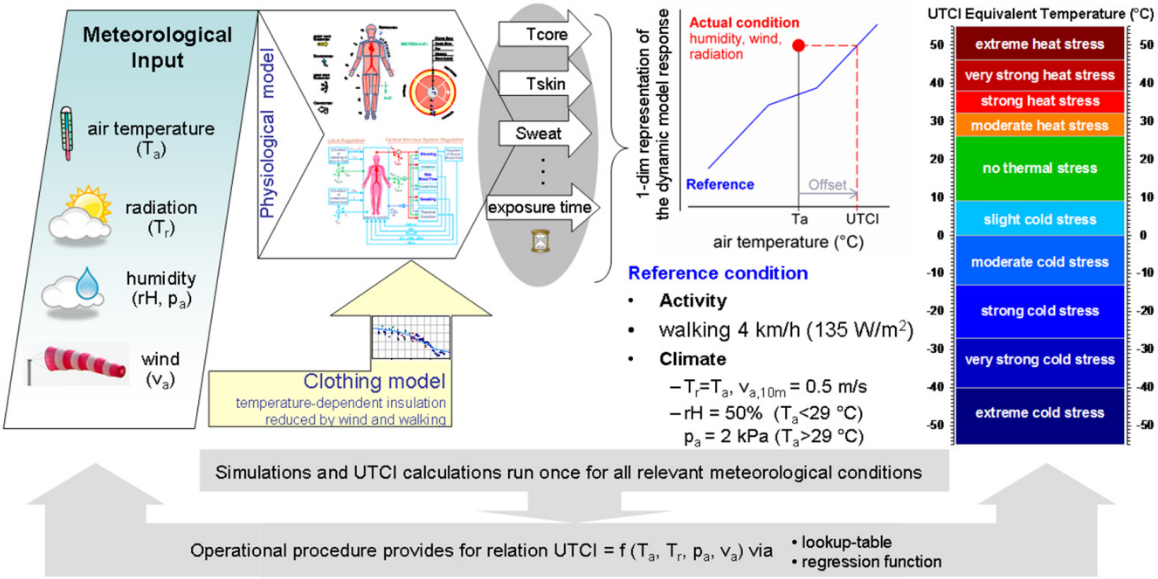

Figure 4. Elements of the operational procedure and concept of UTCI as categorized equivalent temperature derived from the dynamic response of a thermo-physiological model coupled with a behavioural clothing model. From Bröde et al (2013). By kind permission of the authors.

Bröde and colleges (2013) tested the applicability of the UTCI model under cold conditions and analysed the sensitivity of the index in comparison to the WCI and the IREQ model (ISO 11079 - wind in the cold). Their main findings were that the UTCI indicated a stronger influence of wind speed above 3 m/s compared to the WCT. The explanation for this is probably the different assumptions made by both approaches; while the WCI focuses on facial cooling under steady-state conditions, the UTCI considers the dynamic response of the whole body (Brode et al., 2013). The IREQ model also focuses on the whole-body response to cold stress. The IREQ requires far higher values for clothing insulation at a given temperature than the values suggested by the UTCI model. However, for a given level of clothing insulation, the predictions of heat loss by IREQ were in accordance with the dynamic physiological response of the UTCI model. The UTCI provides a valid assessment of human physiological response to thermal stress, ranging from extreme cold to extreme heat. The model is based on recent scientific progress in thermophysiology and biophysical modeling which will enable current limitations of thermal indices to be resolved. However, the UTCI approach still requires significantly more research, e.g., simulations performed by systematically varying factors such as metabolic rate, clothing characteristics and exposure time, in addition to the physical determinants of the thermal environment (Brode et al., 2013).

14.6 The use of the WCI to estimate deterioration in manual performance

The WCI only contains information about the risk of bare skin freezing. Daanen (2009) estimated the deterioration in manual performance in the cold using the WCI. Reduced manual performance is often observed at finger skin temperatures below 15 °C, and Daanen therefore calculated how long it would take to reach a finger temperature of 14 °C while using mittens at different WCT (Table 3). Daanen concluded that WCT may serve as a good indicator for manual performance decrease in combination with exposure duration for the WCT range of 1 to -34°C and exposure durations of up to one hour. WCT values lower than the table values and exposure durations longer than the values in the table are expected to lead to a considerable loss of finger dexterity. To our knowledge only one study exists that have used the WCT to estimate deterioration of manual performance.

Table 3 Combinations of WCT and exposure duration that correspond to estimated finger skin temperature of 14 °C (Daanen, 2009)

Wind chill temperature (WCT)	Exposure duration (min)
-10	>60
-20	37
-30	15
-40	9
-50	5

14.7 Recommended use of WCI

The classification of risk categories from ISO 11079 should be used as a basis guideline for cold stress. We have provided a modified version of risk categories in Table 6 (see chapter 15). ISO 11079 is more conservative (with regards to risk category 1 low risk of frostbite: -10 to -24 °C) compared to the new Environment Canada WCI (low risk of frostbite -10 °C - -27 ° C).

Risk of frostbite is influenced by a number of factors and the assumptions made in the WCI model still have some shortcomings. Based on the broad appliance of the WCI it is better to be on the safe side with regard to threshold values. We therefore consider the more conservative WCT threshold values for risk of frostbites given in ISO 11079 as the safest alternative. This recommendation is based on the following:

- Narrow regions of the body (finger and nose) will cool faster compared to the cheek – the current WCI is based on cheek temperatures.
- Individual differences in time to skin freezing are not included in the current WCI models.
- The working environment can be influenced by local variations in wind, humidity and temperature.
- The risk in cold climate is not only related to frostbite. Deterioration in manual performance and thermal comfort occurs before there is a risk of frostbite.
- ISO 11079 has a well-established scientific and empirical foundation, and potential changes/improvements in risk classifications can be included over time.

For future research work, prediction of times to skin freezing (in essence, safe exposure limits) would be more meaningful and easier to interpret than the WCT. This would also enable direct measures of degraded function (e.g loss of finger dexterity) under moderate conditions and the risk of frostbite in the long term.
See chapter 15 and 16 for recommendation of clothing and protection, duration of exposure on the basis of the WCI and recommendation of work-reheat periods on the basis of the IREQ model.

15 Assessment of existing protective clothing

This part has included assessment of existing clothing concepts in use by petroleum workers today in SINTEF Work Physiology Laboratory, Trondheim with the following sub-goals:

- Calculate insulation values (Clo) on existing clothing (3 clothing concepts) in use by petroleum workers.
- IREQ-analyses including climatic data and different working intensities based on work intensity and clothing used. Calculate the allowable exposure time (duration limited exposure, DLE) and recovery times.
- Recommendations for adequate clothing for different work intensities, exposure times and cold related risks.

The IREQ model

The IREQ model is a heat-exchange model by which the thermal stress associated with work in cold can be evaluated. Based on measurements of air temperature, mean radiant temperature, humidity and air velocity, and measurements or estimates of activity level, the model calculates the clothing insulation required to maintain body heat balance (Holmer, 1988). The required clothing insulation can be used to develop guidelines on how to dress under different environmental conditions and work intensities. The IREQ model also provides estimates for recommended duration of cold exposure and recovery times in order to restore body heat balance. IREQ can also provide useful insight in the design and planning process of work/rest schedules in shift-work regimes.

Guidelines for the use of IREQ are given in ISO 11079 (2007). This standard refers to ISO standards that provide the methodology/procedure/tables for assessing thermal stress associated with exposure to cold environments. The following input to IREQ is needed:

a) measure or estimate air temperature (see ISO 7726);
b) measure or estimate air velocity (see ISO 7726);
c) determine exposure times (ISO 11079);
d) estimate activity level for the calculation of metabolic heat production (see ISO 8996);
e) estimate thermal insulation of clothing (see ISO 9920);
f) calculate $IREQ_{neutral}$ and $IREQ_{min}$ using a computer program (see ISO 11079:2007, Annex F), or graphs
g) compare IREQ with the actual clothing insulation;
h) if clothing insulation is lower than $IREQ_{min}$, calculate the DLE (duration-limited exposure) time.

In the following, the IREQ method was used to evaluate "state of the art" petroleum workers' clothing for cold climates.

15.1 Insulation values of three clothing concepts

At the Statoil LNG installation at Melkøya, a new outer garment clothing concept has been developed and designed especially for the harsh arctic climate. Gore-Tex Pyrad is the new material used in the outer garments, which gives the clothing characteristics very similar to those of traditional shell-layer clothing used in sports and leisure activities. Based on information from personnel at Melkøya, three different clothing concepts were tested in this project (Table 4). The outer garments were similar in all concepts and the alterations in insulation were introduced in the shoes, gloves, headgear and middle layers.
The Clo-value measurements were performed in the SINTEF Work Physiology laboratory in Trondheim. The thermal manikin represents a size 38 woman. The manikin is divided into 16 body segments, which are individually controlled and adjusted by a computer. The manikin was kept in a stationary upright position. The manikin surface temperature was kept at 34 °C for all tests. Air

temperature was measured by three thermistors (YSI 400, Yellow Spring Instruments, USA) located 0.5 ± 0.1 m from the manikin's feet, waist and head. Heat supply ($W \cdot m^{-2}$) and surface temperature were recorded every 10 seconds for each of the 16 body zones. The manikin has been tested and validated through the EU project SUBZERO (2000-2002). The tests were performed in accordance with ISO 15831 in a climate chamber, with ambient conditions of 22 ± 0.5 °C and no wind.

Table 4 Description of the tested clothing concepts. Clo, clothing insulation value (1 Clo unit = $0.155 m^2 K/W$)

	Concept 1	**Concept 2**	**Concept 3**
Recommended Wind Chill temperature	0 °C to -9 °C	-10 °C to -24 °C	-25 °C to -34 °C
Underwear	-Devold Spirit longs -Devold Spirit shirt -Woollen socks	-Devold Spirit longs -Devold Spirit shirt -Woolen socks	-Devold Spirit longs -Devold Spirit shirt -Woollen socks
Middle layer garments		-Devold Protection longs -Devold Protection shirt	-Devold Protection longs -Devold Protection shirt -Wenaas fiber jakcet
Outer garments	-Wenaas Gore-Tex bib -Wenaas Gore-tex jacket	-Wenaas Gore-Tex bib -Wenaas Gore-tex jacket	-Wenaas Gore-Tex bib -Wenaas Gore-tex jacket
Protective head garments	-Devold Spirit buff -Helmet	-Devold Spirit buff -Devold Spirit balaclava -Helmet	-Devold Spirit buff -Proline facemask -L.Brador thick headliner -Helmet
Gloves	Granberg EX Assembly	Granberg EX All-round Winter	Granberg EX All-round Winter
Shoes	Forma Fulmar	Forma Ocean w/thick innersoles	Forma Ocean w/thick innersoles
Total clothing insulation (I_T)	**2.6**	**3.1**	**3.4**
Basic clothing insulation (I_{cl})	**1.7**	**2.2**	**2.6**

15.2 IREQ analysis

The IREQ model was used to evaluate three different clothing concepts at low (100 W/m^2) and moderate (165 W/m^2) work intensities that represented typical workloads during a shift in the petroleum industry. A range of environmental conditions was tested; ambient temperatures from 0 °C to -40 °C at 5 °C intervals and wind velocities of 0.4, 5, 10 and 15m/s. The complete overview of the IREQ calculations is shown in Table 1-6 in Appendix A. Values for wind chill temperatures (WCT) calculated by the formula in Annex D ISO 11077:2007 are added to the tables in Appendix A.

The IREQ model provides recommendations for both basic clothing insulation (Icl) and the resultant clothing insulation or insulation required (IREQ). Icl is the most commonly reported insulation value of a clothing ensemble and specifies the insulation value under standardised (static, wind-still) conditions (ISO 11079). The presented Clo values in Table 4 are total clothing insulation (Icl + air boundary layer). The IREQ value defines the actual insulation provided by clothing under given conditions. The combination of air permeability of the outer garments, wind, body movements and fit can reduce clothing insulation (Havenith et al., 1990, Havenith and Nilsson, 2004). In practical terms this means that a high wind does not increase the IREQ to a great extent, but rather increases the Icl required.

Both IREQ and Icl are expressed by minimum and neutral values. The minimum value will accept a high physiological strain and the neutral value represents low physiological strain. The interval between the minimum and neutral value can be seen as the clothing regulatory zone, within which each individual can regulate their preferable insulation.

In Figure 5, $IREQ_{neutral}$ values are presented as a function of low (dashed line) and moderate (solid line) work intensities at four wind speeds. Since the IREQ value includes wind and movements (resultant clothing insulation), there are small variations due to wind. However, an increase in metabolic heat production of 65 W/m^2 led to a considerably lower IREQ value. Variations in work intensity are usual throughout a typical working shift. It has been assumed that the range of a suitable clothing insulation can be as much as 2 Clo for the same person in one shift (Griefahn, 2000). It is not possible to change clothing so frequently during the shift, which means periods of heat stress, sweating and wetting of clothing. At the highest workloads sweat is likely to accumulate in the clothing, thereby reducing insulation. The IREQ model does not take this into consideration, and a correction factor for such workloads would appear to be appropriate (Griefahn, 2000).

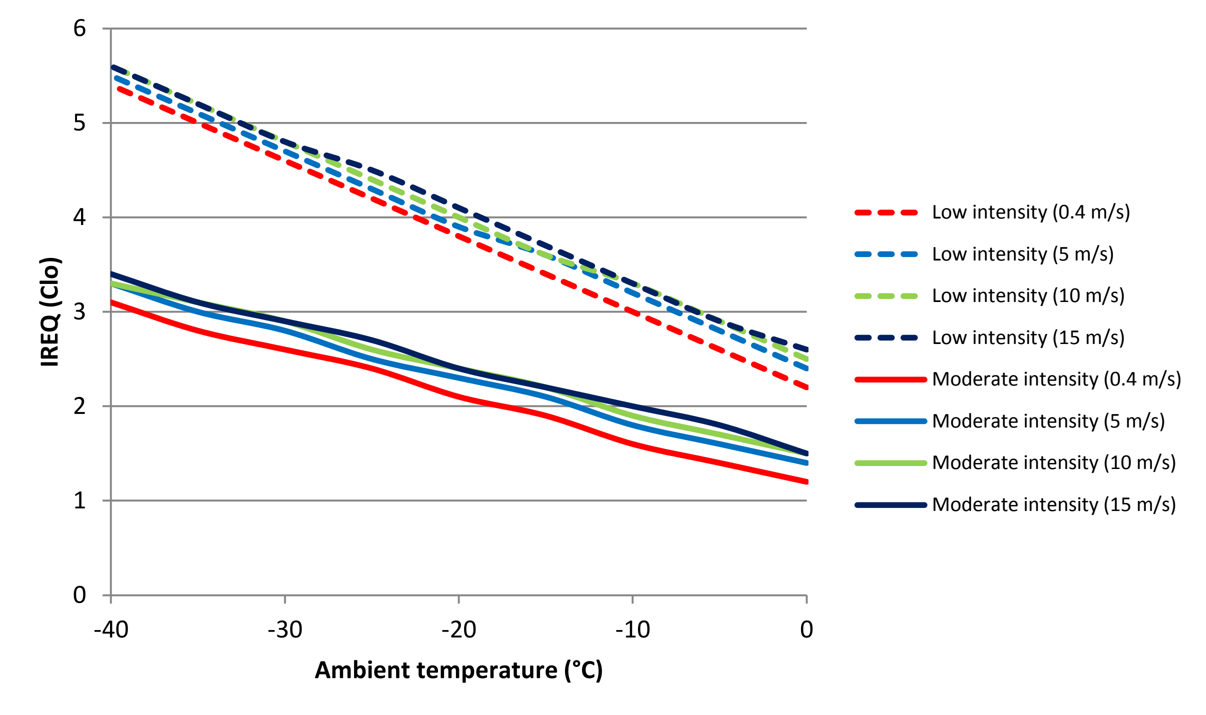

Figure 5 $IREQ_{neutral}$ as a function of low and moderate work intensities at four wind speeds.

Wind can have a profound negative effect on clothing insulation. Wind is an important factor in the IREQ calculations. Figure 6 shows the $IREQ_{neutral}$ (solid line) and $Icl_{neutral}$ (dashed line) at different wind speeds. The IREQ value is a resultant clothing insulation value that includes the effect of wind and movement, where Icl does not include these parameters. We can therefore observe a progressively larger difference between IREQ and Icl values as wind speed increases.

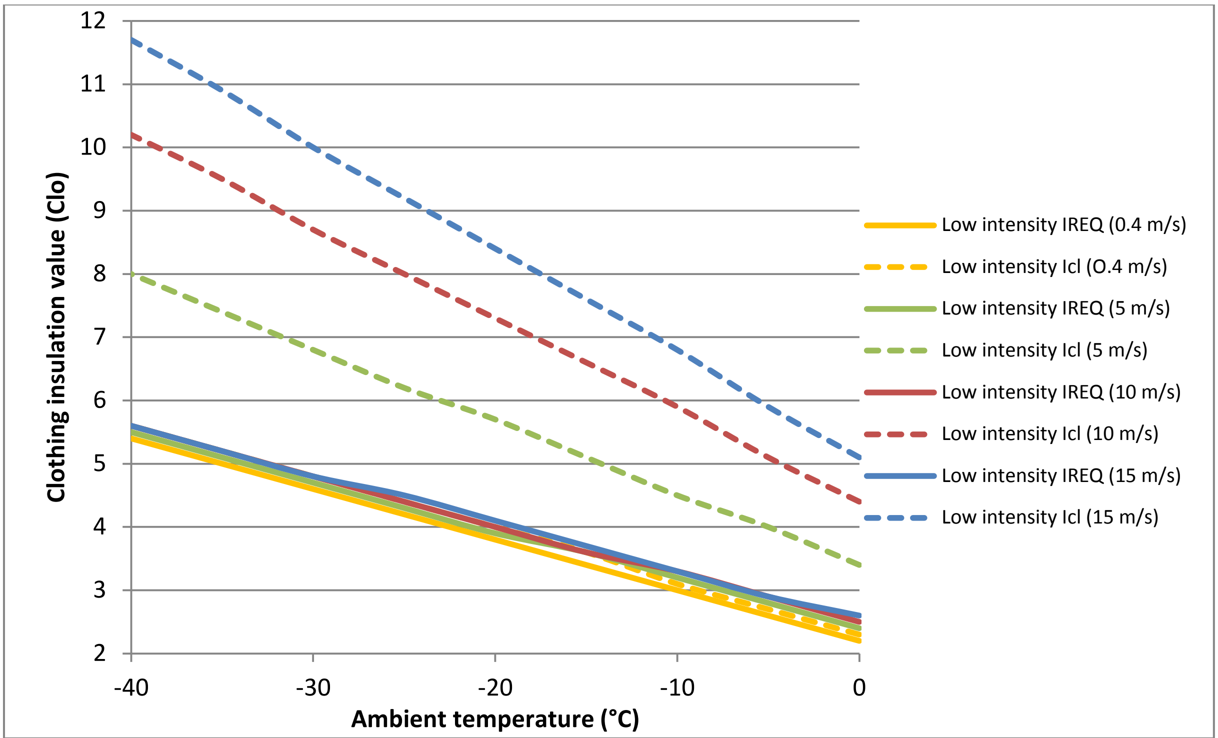

Figure 6 $IREQ_{neutral}$ and $Icl_{neutral}$ and different ambient temperatures and wind speeds.

The IREQ model does not take gender differences into account. It is generally considered that women have a greater subjective sensitivity to cold than males. However, women often have a higher physiological insulation provided by their subcutaneous fat, which favours their thermal abilities in the cold. Although there are still mostly males in these occupational settings, since the proportion of women is increasing, a suitable female correction factor should be included in the IREQ model in the future.

15.3 Allowable exposure time

The IREQ model also provides information about recommended exposure time. When the clothing selected or used provides less than the calculated required insulation (IREQ), exposure has to be limited in time in order to prevent further body cooling. The IREQ model allows for a certain reduction in body heat content (144 kJ·m^{-2}), and with this threshold value it is possible to calculate the duration of limited exposure (DLE). Like IREQ and Icl, DLE also calculates minimum and neutral values. The minimum value will accept a high physiological strain and the neutral value represents low physiological strain. DLE is presented for the different clothing concepts, work intensities and environmental conditions in Figure 7 and Figure 8. A complete overview of all the calculated DLE values can be found in Appendix A.

The example shown is for all clothing concepts at wind speeds of 5 m/s. The solid line represents the $DLE_{neutral}$ where thermal strain is low, and the dashed line represents DLE_{min} where thermal strain is high. In Figure 8 we can observe the great effect of increased work intensity on duration of exposure compared to Figure 7. The three different concepts tested in this project overlap, as is shown by the overlapping of the solid and dashed lines. This indicates that the clothing provides a sufficient range of insulation to maintain acceptable thermal comfort at moderate work intensities for users within the threshold values derived from the IREQ model. However, DLE at low work intensity is rather short, and the recommended exposure period is less than one hour for ambient temperatures between -40 to -10 °C at 10 m/s wind speed. These calculations are based on continuous work intensity and environmental exposure, which may not be the case during a typical work shift.

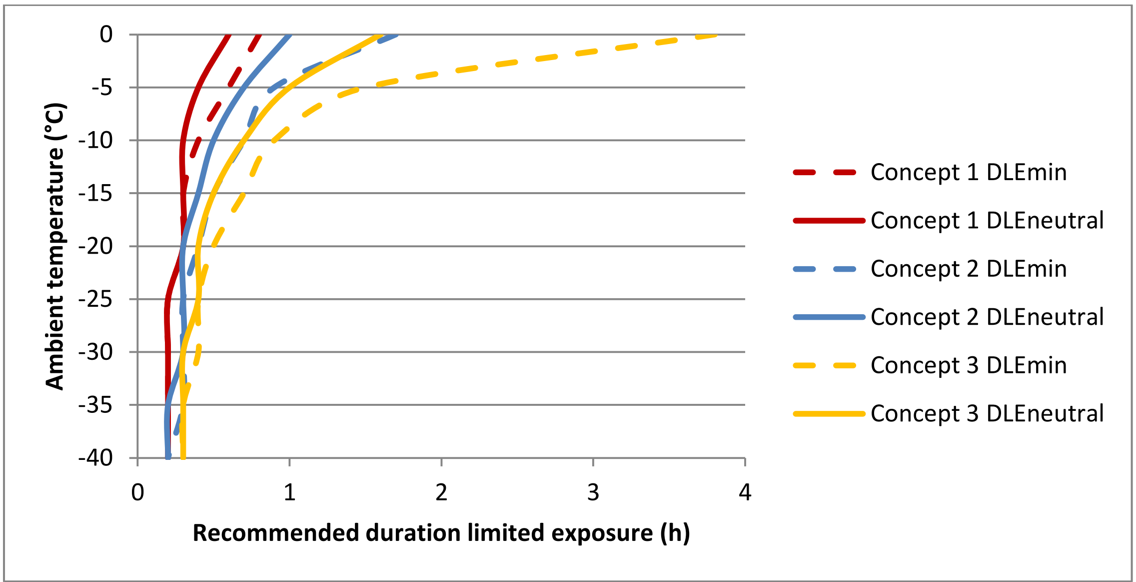

Figure 7 Duration of limited exposure with low (100 W·m^{-2}) work intensity.

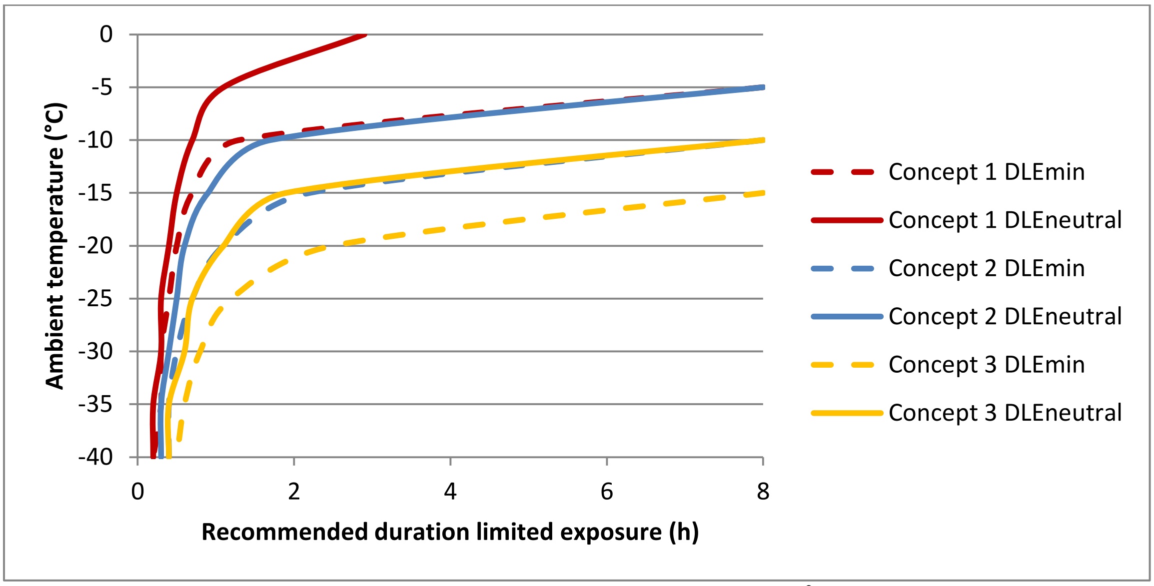

Figure 8 Duration of limited exposure with moderate (165 W·m^{-2}) work intensity.

15.4 Conclusion from the validation of the protective clothing

The protective clothing tested in this project provides sufficient thermal protection with regard to maintaining body and core temperature. The level of metabolic heat production is often more crucial than the insulation value of the protective clothing as a means of maintaining thermal balance during a work shift. At low metabolic heat production workers will experience substantial cold stress after approximately 1.5 hours at -5 °C and 5 m/s wind. With moderate heat production, an ambient temperature of -20 to -25 °C and similar wind speed is tolerable for 1.5 hours of exposure. If continuous work shifts are longer, or environmental conditions worsen, an even better insulated outer garment is recommended. Long periods of standing still should be avoided, and the importance of effective work routines should be emphasized during periods of extreme environmental conditions. The recommendations provided by the IREQ model (ISO 11079) can serve as basic guidelines that each individual can use, and in that manner further expand their range of tolerance of environmental conditions as their level of skill and experience improve.

16 Required protection related to the work intensity, risk of frostbite, contact cooling and duration of cold exposure based on the WCI and IREQ

Objective
- Define the required protection related to the type of work (inspection vs. operability and the possibility of coming into direct contact with cold metal).
- Draw up guidelines for recommended use of wind chill temperature to help decide when to use weather protection, recommended work/reheat period and need for special protection equipment (PPE)

Reference document WERA Appendix A, Annex 1 (Statoil internal document).

A work environment cold risk assessment method is described in the WERA document. It can be kept as a general guideline for work in cold climate with the following modifications:

1. Hypothermia (defined as core temperature below 35°C) is a condition that is very unlikely to occur in a working situation in cold climate, but can occur in case of an accident. We recommend removing the sections describing hypothermia as a risk factor in a **normal working situation**.
2. For assessment of cold risk by WCI, quantification of required clothing, duration of exposure and recovery time, we recommend using the ISO standards available:
    a. ISO 8996:2005 Table C1 Classification of metabolic rate
    b. ISO 11079:2007 Annex D: Determination of wind cooling
    c. ISO 11079:2007 Annex E: Determination of required clothing insulation (IREQ), duration of cold exposure and recovery time.
    d. ISO 13732-3: Conductive cooling
3. The following updated text and tables should be included:

16.1 Risk classification

On the basis of ISO 11079:2007 and with the consideration of the new Environment Canada WCI, Table 5 presents a modified version of the classification of risk categories. In order to simplify use, the risk class is presented as colored codes directly in each table.

Table 5 Classification of risk categories, wind chill temperature, risk of frostbite and recommended limits for work (modified from ISO 11079: 2007)

Classification of risk	Wind chill temperature°C	Risk	Recommended limits for work
0	<-9	Low risk, < 5% chance of frostbite for most people	Normal work; emergency work; planned maintenance
1	-10 to -24	Low risk, < 5% chance of frostbite for most people, uncomfortable cold	Normal work (reduced work periods); emergency work
2	-25 to -34	Moderate risk, increasing risk of frostbite for most people in 10- 30 minutes*, very cold	Normal work (reduced work periods); emergency work
3	-35 to -59	High risk, risk of frostbite for most people in 2-10 min*, bitterly cold	Emergency work only
4	-60 and colder	Extreme risk, risk of frostbite for most people in 2 minutes or less*, extremely cold	No work outside

*In sustained winds over 50 km/h, frostbite can occur sooner than indicated

16.2 Wind Chill Index

The danger of frostbite to exposed skin can be evaluated using the wind chill index (Table 6). The wind chill temperature (WCT or t_{WC}) is determined by the equation given in ISO 11079:2007 (D.1):

$$t_{WC} = 13{,}12 + 0{,}6215 \cdot t_a - 11{,}37 \cdot v_{10}^{0{,}16} + 0{,}3965 \cdot t_a v_{10}^{0{,}16}$$

Wind velocity (v_{10}) is defined as the standard meteorological value measured 10 m above ground level. This value is obtained from weather stations and weather forecasts. If the local wind velocity at ground level is measured, it must be multiplied by 1,5 before it is inserted in the equation.

Suggestion of requirement:
The wind chill temperature shall be continuously monitored in open and semi-open areas for installations where it is expected that WCT below -10 °C occur and the duration of outdoor activity is expected to exceed 40 minutes. These areas should be identified in the design stage of the planning and risk assessment of cold exposure.

Table 6 Wind chill index: Cooling of bare skin in a combination of wind and temperature (ISO 11079:2007)

Wind scale	Wind speed		Ambient temperature (°C)										
Beaufort ($m \cdot s^{-1}$)	$Km \cdot h^{-1}$	$m \cdot s^{-1}$	0	-5	-10	-15	-20	-25	-30	-35	-40	-45	-50
Light breeze (1.6-3.3)	5	1.4	-2	-7	-13	-19	-24	-30	-36	-41	-47	-53	-58
	10	2.8	-3	-9	-15	-21	-27	-33	-39	-45	-51	-57	-63
Gentle breeze (3.4-5.4)	15	4.2	-4	-11	-17	-23	-29	-35	-41	-48	-54	-60	-66
	20	5.6	-5	-12	-18	-24	-31	-37	-43	-49	-56	-62	-68
Moderate breeze (5.5-7.9)	25	6.9	-6	-12	-19	-25	-32	-38	-45	-51	-57	-64	-70
	30	8.3	-7	-13	-20	-26	-33	-39	-46	-52	-59	-65	-72
Fresh breeze (8.0-10.7)	35	9.7	-7	-14	-20	-27	-33	-40	-47	-53	-60	-66	-73
	40	11.1	-7	-14	-21	-27	-34	-41	-48	-54	-61	-68	-74
Strong breeze (10.8-13.8)	45	12.5	-8	-15	-21	-28	-35	-42	-48	-55	-62	-69	-75
	50	13.9	-8	-15	-22	-29	-35	-42	-49	-56	-63	-70	-76
Near gale (13.9-17.1)	55	15.3	-9	-15	-22	-29	-36	-43	-50	-57	-63	-70	-77
	60	16.7	-9	-16	-23	-30	-37	-43	-50	-57	-64	-71	-78
	65	18.1	-9	-16	-23	-30	-37	-44	-51	-58	-65	-72	-79
Gale to huricane (> 17.2)	70	19.4	-9	-16	-23	-30	-37	-44	-51	-59	-66	-73	-80
	75	20.8	-10	-17	-24	-31	-38	-45	-52	-59	-66	-73	-80
	80	22.2	-10	-17	-24	-31	-38	-45	-52	-60	-67	-74	-81

Table 7 provides a recommendation of duration of exposure, risk of frostbite and preventive measures based on the WCT.

Table 7 Recommended duration of exposure and preventive measures based on the wind chill temperature.

WCT	Risk of frostbite	Duration of cold exposure	Preventive measures
10 to -9	0: Low risk < 5% chance of frostbite for most people	Unlimited	• Dress warmly • Stay dry • Awareness if manual operations with bare hands has to be performed outdoors
-10 to -24	1: Low risk < 5% chance of frostbite for most people Uncomfortable cold	40-120 minutes	• Dress in layers of warm clothing, with an outer layer that is wind-resistant. • Wear a hat, mittens or insulated gloves, a scarf and insulated, waterproof footwear. • Stay dry. • Keep active • Awareness if manual operations with bare hands has to be performed
-25 to -34	2: Moderate risk Increasing risk of frostbite for most people in 10- 30 minutes Very cold,	10-30 minutes*	• Dress in layers of warm clothing, with an outer layer that is wind-resistant • Minimize exposed skin (facemask and goggles) • Wear a hat, mittens or insulated gloves, a scarf, neck tube or face mask and insulated, waterproof footwear • Stay dry • Keep active • Take brakes and drink warm drinks • Check face and extremities for numbness or whiteness – buddy control
-35 to -59	3: High Bitterly cold, High risk of frostbite for most people in 2-10 min	0-10 minutes*	• Dress in layers of warm clothing, with an outer layer that is wind-resistant. • Cover all exposed skin (facemask and goggles) • Wear a hat, mittens or insulated gloves, a scarf, neck tube or face mask and insulated, waterproof footwear. • Be ready to cut short or cancel outdoor activities. • Stay dry • Keep active. • Take brakes and drink warm drinks • Check face and extremities for numbness or whiteness – buddy control. • Perform risk assessment before each work task
-60 and colder	4: Extreme Extremely cold. High risk of frostbite in most people in 2 minutes or less	Extreme risk, risk of frostbite for most people in 2 minutes or less*, extremely cold	• No work outside

*In sustained winds over 50 km/h, frostbite can occur sooner than indicated

16.3 Recommended duration of cold exposure

When knowing the insulation value of the clothing and the work intensity (estimated from ISO 8996 Table C1), the IREQ model can be used to estimate recommended duration of cold exposure at different ambient temperatures (ISO 11099:2007). When work intensity (metabolic heat production) increases the cold stress can be sustained for a longer period and the recommended duration of cold exposure is extended. Table 8 provides information of recommended duration of cold exposure at **light work intensity** when wearing a clothing concept with a basic clothing value of 2.6 Clo, while Table 9 recommend duration of cold exposure at **moderate work intensity**. A complete overview of all the calculated DLE values for the clothing concepts tested in this project can be found in **Appendix A.**

The duration limited exposure corresponds to time it takes to reach a conditions under which the body can no longer maintain body heat balance, skin temperature starts to decline and you will be thermally uncomfortable. This is not to be confused with the risk of frostbite, but rather used as a guideline for when you should go inside and warm up – before you get too cold.

Table 8 Maximum (DLE_{lim}) recommended duration of cold exposure (hours:minutes) rounded to nearest 15 minute interval at light work intensity with clothing concept 3 (2.6 Clo).

Wind speed $m \cdot s^{-1}$	Ambient temperature (°C)								
	0	-5	-10	-15	-20	-25	-30	-35	-40
0.4	08:00	08:00	08:00	02:15	01:15	01:00	00:45	00:30	00:30
5	03:45	01:30	01:00	00:45	00:30	00:30	00:30	00:15	00:15
10	01:00	00:45	00:30	00:30	00:15	00:15	00:15	00:15	00:15
15	00:45	00:30	00:30	00:15	00:15	00:15	00:15	00:15	00:15

Table 9 Maximum (DLE_{lim}) recommended duration of cold exposure (hours:minutes) rounded to nearest 15-minute interval at moderate work intensity with clothing concept 1 (2.6 Clo).

Wind speed $m \cdot s^{-1}$	Ambient temperature (°C)								
	0	-5	-10	-15	-20	-25	-30	-35	-40
0.4	08:00	08:00	08:00	08:00	08:00	08:00	08:00	04:00	01:45
5	08:00	08:00	08:00	08:00	02:30	01:15	00:45	00:30	00:30
10	08:00	08:00	03:00	01:00	00:45	00:30	00:30	00:15	00:15
15	08:00	03:30	01:00	00:45	00:30	00:30	00:15	00:15	00:15

16.4 Recovery times

ISO 11079:2007 can be used for estimation of recovery times defined as an estimate of how much time indoor is required to restore normal body heat balance after cold exposure. Recovery times are dependent on the ambient conditions of the recovery room, metabolic heat production during recovery and the available basic insulation. Table 10 provides information about recovery times at different indoor temperatures.

When working in the cold it is important to maintain a sensible work, warm-up and rehabilitation regime. An example of such a work and warm-up regime is presented in OGP 398. These guidelines apply to moderate to heavy physical work in any four-hour period. However, the "warmest" range of ambient temperatures presented in OGP 398 is -26°C to -28°C. Such low temperatures, in combination with wind, result in a wind chill temperature lower than recommended for outdoor work, and an increased risk of frostbite (Barents 2020, NORSOK S-002 and ISO 11079). The guidelines in OGP

398 do not describe the amount of clothing insulation used, or allow for new calculations with different clothing insulations.

In ISO 11079, recovery times offer an estimate of how much time is required to restore normal body heat balance after cold exposure. Recovery times are calculated based on a loss of body heat content of 144 $kJ \cdot m^{-2}$, and are dependent on the ambient conditions of the recovery room, metabolic heat production during recovery and the available basic insulation. The typical situation during a recovery period is that workers take off some outerwear and middle layers and sit down in the break. This lowers their metabolic rate and reduces clothing insulation. If the goal of a recovery period is to restore thermal balance before another exposure period, some form of physical activity would reduce recovery time. In this example we have chosen two levels of metabolic heat production, rest (65 $W \cdot m^{-2}$) and standing (90 $W \cdot m^{-2}$) in combination with a very warm (35°C) and a normal (25°C) restroom temperature. The very warm restroom temperature was selected to provide an example on how much can be gained by using a very warm restroom. Three different clothing insulation levels were selected; normal office clothing (1 Clo), outdoor work clothing without outer garment and middle layer (1.5 Clo) and outdoor clothing without outer garment (2 Clo). An overview of the calculated recovery times required is shown in Table 10.

Table 10 Recovery times (rounded to nearest 15 minutes) to restore normal body heat balance at various ambient temperatures, metabolic rates and clothing insulation levels.

Indoor Air temperature (°C)	Metabolic rate ($W \cdot m^{-2}$)	Insulation value (Clo)	Recovery time (hours: minutes)
25	65	2.0	01:15
25	65	1.5	01:45
25	90	1.0	01:00
35	65	2.0	00:30
35	65	1.5	00:30
35	90	1.0	00:30

16.5 Cold surfaces

Contact between bare skin and cold surfaces is likely to occur in a wide range of industrial settings.. This contact may be intentional or accidental and can affect small skin areas such as a fingertip or larger areas such as the palm of the hand (Geng et al., 2006). Cold contact exposure can be regarded a health and safety risk and should therefore be included in risk assessments of cold workplaces (Henriksson et al., 2009). The specifications for surface temperature limiting values, described in ISO 13732-3, were developed by five different laboratories in the European "ColdSurf" research project (EU Project SMT4-CT97-2149). Optimal hand function is dependent on skin temperature, with deterioration in manual performance combined with pain sensation occurring at skin temperatures lower than 15 °C, deterioration of tactile sensation and numbness at skin temperatures lower than 8°C and risk of frostbite at skin temperatures below 0 °C. Depending on the rate of skin cooling, the estimated freezing point of human finger skin is -0.6 °C or below (Geng et al., 2006). The most effective preventive measure is to limit the exposure of bare skin to particularly cold metallic surfaces. Awareness of limit values before frostbite could occur and of the value of continuous use of protective gloves during periods of low ambient temperature will protect workers against cold injury, numbness and pain.

ISO 13732-3:2005 provides a predictive model that includes the effects of material thermal properties and surface temperature, threshold for finger and hand contacting cold surfaces; that enables us to establish limit values for contact with different cold surfaces. The standard provides criteria for the evaluation; pain sensation, numbness and frostbite. ISO 13732:2005 (part 3) provides information about surface temperatures of a range of materials that may be touched and examples of contact periods that can be used in cold risk assessment. The assessment of risk of contact cooling should be made on the basis of: 1) contact period specified, 2) surface temperature of the material/tool. Time of contact can be determined on the basis of observations or other relevant information. Example of contact times are given in Table 11. The maximum contact time for cooling of the palm of the hand to around 15 °C (at which a subjective sensation of pain at the contacting skin will be experienced) for some materials is shown in Table 12. In ISO 13732-3 five materials have been chosen to represent the broad range of thermal properties; aluminium, steel, stone, nylon and wood. Non-metallic materials like wood and nylon have a much lower thermal conductivity than metals such as steel and aluminium, which pose the highest risk of skin damage, with skin temperatures of 0 °C occurring within 15-20 seconds of contact at material temperatures as high as -4 °C and within 2-6 seconds at -15 °C (Geng et al., 2006). Touching materials like wood and nylon does not raise the risk of frostbite in the range of surface temperatures from -40 to 0 °C. However, onset of numbness can occur within 15-65 seconds of contact at -35 °C and onset of cold pain within five seconds of contact at -20 °C. More detailed graphs for different materials and hand or finger contacting cold surfaces are provided in ISO 13732-3 (2005). Tools and materials of steel and aluminum should not be handled without gloves at temperatures below -5 to -10 °C. Even light contact between a fingertip and cold materials can cause pain, numbness and frostbite within seconds (contact with aluminum and steel at temperatures below 0°C).

Table 11 Examples of contact period (from ISO 13732-3:2005)

Contact period up to	Examples for touching a cold surface	
	Intentional	**Unintentional**
1 s		Touching of a cold surface and quick removal following pain sensation
3 s	Activation of a switch, pressing a button or removing a small spare part with fingertips	Touching of a cold surface for extended reaction time
10 s	Prolonged activation of a switch, slight adjustment of a handle, hand wheel or valve or handling spare parts with fingers and hands	Falling against a cold surface with slow recovery
100 s	Work with a hand wheel, handle, valve or screw bolt-nut etc. withfingers gripping and hands	After slipping and falling accidents on cold surfaces, victim is unable to get up
20 min or longer	Use of hand tool, control elements, handles etc. with hand gripping	

Table 12 Maximum time (sec) for cooling of hands until pain sets in (15 °C) when gripping cold materials with the whole hand without insulating gloves (from ISO 13732-3).

Material type	Surface temperature of material/tool °C							
	5	0	-5	-10	-15	-20	-25	-30
Aluminium	>15	7	<1	<1	<1	<1	<1	<1
Steel	>15	6	2	<1	<1	<1	<1	<1
Rock	>15	10	5	3	1	<1	<1	<1
Nylon	>15	13	10	7	5	4	3	2
Wood	>15	15	11	9	7	5	4	3

16.6 Recommendations

Guideline for the use of WCT

Table 7 provides a guideline for recommended duration of outdoor exposure, risk of frostbite and preventive measures (clothing and protection, buddy system, physical activity) based on the wind chill temperature (WCT). This can be used as a general guideline; however the recommended outdoor exposure time is strongly dependent on the insulation in the clothing and level of activity. If work is to be performed outdoor in extreme cold situations it is recommended to use the IREQ model to get more exact information of required protection, duration of outdoor exposure and recovery times for each case. This should be done as part of a cold risk assessment. Classification of risk categories for frostbite is presented in Table 5 (modified from ISO 11079:2007).

Required protection

The IREQ model (ISO 11079) provides a tool for determination and interpretation of cold stress. It is recommended to estimate the required protection on the basis of the IREQ model as part of a cold risk assessment. The required protection must be identified in each case on the basis on available clothing and protection, outdoor temperature and activity level/tasks to be performed.

Recovery times

ISO 11079:2007 can be used for estimation of recovery times defined as an estimate of how much time indoor is required to restore normal body heat balance after cold exposure. Recovery times are dependent on the ambient conditions of the recovery room, metabolic heat production during recovery and the available basic insulation. Table 10 provides examples of recovery times when either resting or standing in combination with a very warm (35°C) or normal indoor temperature (25°C) wearing variable clothing insulation. It is recommended that a recovery time is estimated in each case on the basis of the access too indoor facilities for warming and clothing used (as part of cold risk assessment).

Contact cooling – cold surfaces

ISO 13732-3:2005 provides a predictive model that includes the effects of material thermal properties and surface temperature, threshold for finger and hand contacting cold surfaces; that enables us to establish limit values for contact with different cold surfaces. It is recommended to use this standard whenever there is risk of contact cooling with cold materials. This should be done as part of a cold risk assessment (see chapter 17).

17 Assessment and management of risk in cold workplaces

Objectives:
Identify models for assessing and managing cold-induced health and safety risks at work.

Define a method for risk assessment for outdoor work in cold climates; determine when the method should be used and what the minimum factors to be included are.

Reference documents:
- ISO 15743:2008. Ergonomics of the thermal environment - Cold workplaces - Risk assessment and management
- ISO 12894: 2001. Ergonomics of the thermal environment - Medical supervision of individuals exposed to extreme hot or cold environments.
- ISO 19906: 2010. Petroleum and natural gas industries — Arctic offshore structures.
- NORSOK STANDARD S-002 (Rev. 4 August 2004). Working environment.
- OGP report no. 488. Performance indicators for fatigue risk management systems, Guidance document for the oil and gas industry (2012).
- OGP report no. 343. Managing health for field operations in oil and gas activities (2011).
- OGP report no. 398. Health aspects of work in extreme climates. A guide for oil and gas industry managers and supervisors (2008).
- Barents 2020 RN05 Working Environment – Barents Sea - stage 4 (Veritas, 2010)
- Working Environment. Health Safety and Environment. Technical and professional requirement. TR 0926, 2012-03-05 (Statoil Internal Document).
- WEHRA – Working Environment Health Risk Assessment. 2010-02-01 (Statoil Internal Document).

Risk assessment definition
A risk assessment is a process designed to assess whether a site needs to implement controls to reduce the risk to an acceptable level. It involves recognizing the hazard, evaluating the associated risk, assessing the effectiveness of existing controls, and identifying whether additional controls are needed (OGP 488).

17.1 Models for cold risk assessment

Arctic environmental conditions will have a powerful influence on the workings environment and safety of operations (Veritas, 2010). Knowledge of the risk factors inherent in working in the cold is a prerequisite for being able to draw up a work environment design for operations in the Arctic. However, risks associated with cold work are complex and may require wide-ranging investigations. A number of methods have been developed for assessing and managing cold-induced health and safety risks in the workplace (Holmer et al., 2007, Afanasieva et al., 2009, Risikko et al., 2003, Malchaire et al., 1999, Risikko, 2009).

There are several studies of risk assessment of workers in cold climates. Päivinen (2006) studied electricians working in high places. Working on pylons can be especially demanding in cold winter climates. This study used questionnaires and interviews to evaluate workers' perception of work-related risks, with special reference to the use of hand tools. Electricity transmission, ice, and equipment falling from masts were the greatest perceived risks, and preventing such occurrences is important for safety improvements. This study provides information for improving work safety and ergonomics standards, especially in telecommunications and electricity transmission tasks (Päivinen, 2006). Virokannas et al (1994) studied health risk assessment of noise, hand-arm vibration and cold in railway track maintenance. The results showed that there are many limitations in the health risk assessment methods in current use, e.g**. behaviour** and **protection facilities** had a great influence on the risk of frostbite. The study showed that the predicted risk was higher than the clinically observed risk. For example the predicted risk of hearing damage was 24%, but the observed value in a clinical study was only 15%, thanks to the use of hearing protectors. The prevalence of vibration-induced white finger (14%) was predicted quite well by the ISO 5349 standard, but no method was available to assess the risk of nerve disorders. The results of this study also showed how important it is to take preventive and contributory factors into account when the health risks of cold are being assessed.

As mentioned in the introductory chapter, the effects of cold on human beings are mainly dependent on the four basic environmental variables (air temperature, wind-speed, humidity and radiation), the level of activity and the clothing used. Extreme climatic conditions in the Arctic in combination with other factors (snow, ice, remoteness, darkness, etc.) increase the stress level and the risk of accidents. Protective clothing is the most natural means of protecting oneself against the cold harsh climate in the Arctic. However, cold-weather clothing and protective equipment can be bulky and uncomfortable, affecting performance and increasing muscle strain and work-load (Holmer, 2009). Cold endangers the body's heat balance and requires countermeasures (e.g clothing, work-rest schedules/shielding/behavioral actions etc.) to control heat loss. Depending on the level of cooling (local/whole body), the human response to outdoor cold exposure ranges from discomfort, reduced muscular and cognitive performance to cold injury. The actual risk associated with this depends on individual factors (gender, age, health, fitness, degree of acclimatization etc.) and level of experience. Figure 9 summarizes the relationship between climate, thermal stress and risk associated with this. Predictive models (e.g WCI, IREQ, UTCI), behavioral responses, training, education and organizational actions are all important factors in defining risk assessment for outdoor work in cold climates.

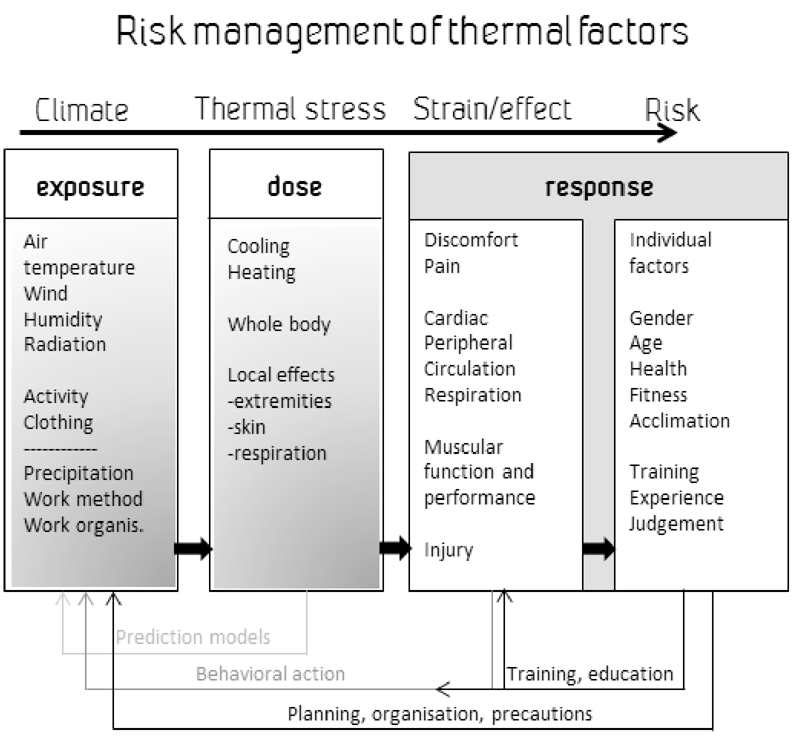

Figure 9 Relationship between climate, stress, strain and risk assessment (modified from Holmer 2000).

If we are to meet the environmental challenges presented by the Arctic environment, the level of cold exposure and associated risks must be **identified, evaluated and controlled** in a systematic way. The following paragraphs discuss the available methods presented by the ISO standards for risk assessment of cold problems.

17.2 ISO standards for cold risk assessment

International standards are readily available for assessment of various types of cold stress and can be incorporated in a risk management programme (Holmér, 2008). ISO standards provide guidelines to assessment and evaluation methods for the thermal environment that can be used to assess risks associated with work in cold climates. ISO 15743 (2008) describes a practical and usable means of identifying and assessing cold risks, while ISO 12894 (2001) provides information for cold-risk health checks and medical supervision. The most frequently used standard for assessing cold risk is ISO 11079 (2007), which includes both the wind chill index and the required clothing insulation index (IREQ), described earlier (see chapter 13-15). Figure 10 presents the interaction between the ISO standards:

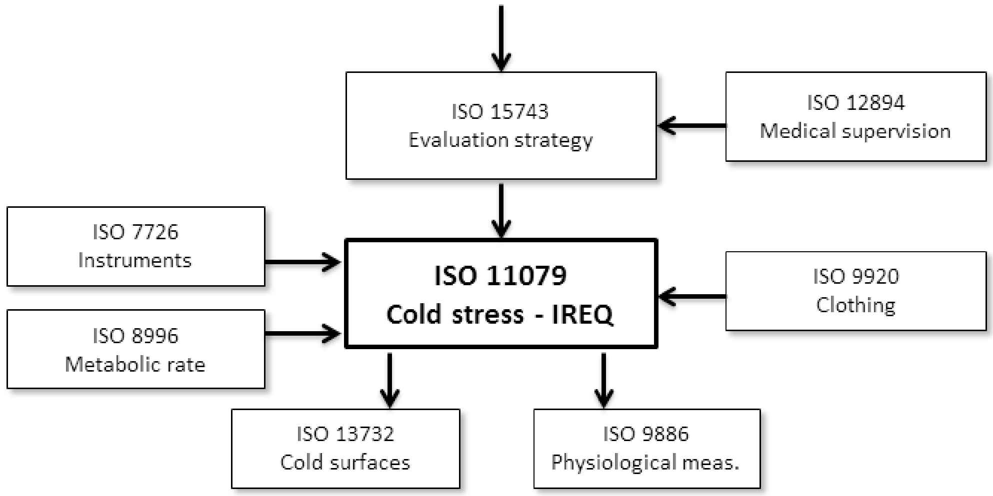

Figure 10 Overview of standards applicable to cold environments.

17.2.1 Cold risk assessment (ISO 15743)

A suggestion of appropriate occupational cold-risk management is provided in ISO 15743. This includes both organizational and technical measures in work-place. The model was originally developed by a network of scientific institute's through the Barents Interreg IIA-Programme 1999-2001 (Hassi et al., 2001a) (Figure 11). This project was based on the need for a systematic and comprehensive method for assessing the effects of cold on health and safety. A methodology was developed to incorporate cold as a factor in occupational health care and workplace management. The results of this work and other cold investigation studies resulted in a new standard: ISO 15743 (2008).

The concept behind ISO 15743 is a stepwise strategy for evaluation of cold-related problems depending on their level of complexity (Holmér, 2008). The principal idea is to assess and solve such problems by means of as simple methods as possible. This may be carried out by work-place safety representatives. Only when problems become complex and require costly preventive measures will wider-ranging studies and measurements be carried out by qualified experts. The practical methods and models described in this standard have been tested by target companies in the Barents region (construction, forestry and the fish-processing industry) (Hassi et al., 2001b).

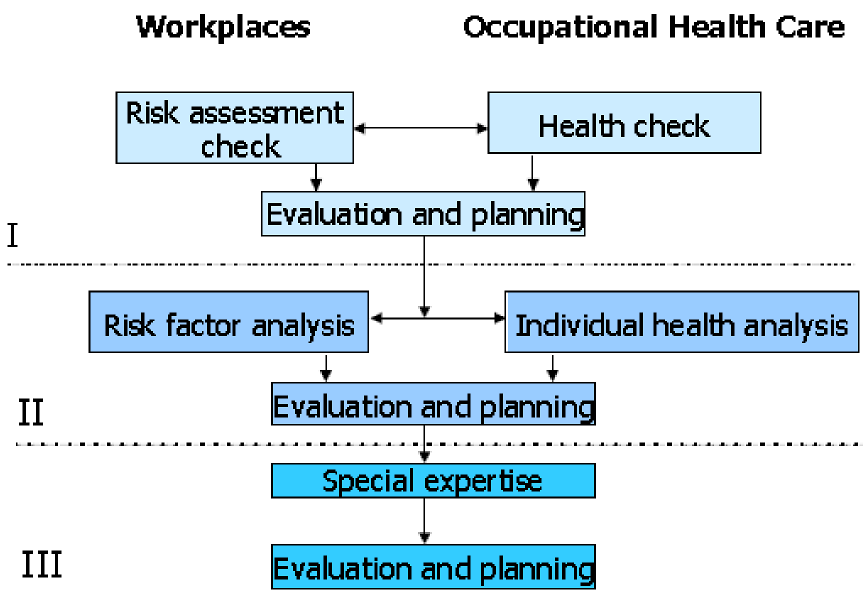

Figure 11 Risk assessment and management of cold related hazards in arctic workplaces. Network of scientific institutes improving practical working acticities. Barents Interreg IIA-Programme 1999-2001. From Hassi J et al (2001).

A holistic systematic approach to risk assessment of cold-related problems is presented in ISO 15743 (2008):

Identification of cold hazards - observations (stage 1):
In **stage one**, simple observation techniques are used to identify and solve obvious and easy problems. The standard provides a simple checklist with questions to be used during planning, a few times during the winter and if the type of work involved changes significantly.

<u>Collecting qualitative information by observation (ISO 15743 §5.2 and Annex A):</u>
The checklist in Annex A provides a simple evaluation scheme and scoring (0: no need for corrective actions, 1: corrective actions are recommended in the long run, 2: immediate need for corrective actions). The checklist of cold-related problems should include at least the topics mentioned in Annex A (ISO 15743).

<u>Minimum to be included in the cold risk assessment checklist (modified from (Hassi et al., 2001c)):</u>
Are these conditions causing problems with cold? (No, Yes - slight problem/ Yes – severe problems):

- exposure to cold air
- degree of contact with cold materials
- degree of exposure to wetness
- problems related to the cold protective clothing ensemble
- problems related to protecting the extremities (hands, feet and head)
- problems related to using personal protective equipment (e.g. hearing equipment) together with cold protective clothing
- slipperiness
- icing/falling ice
- snow drift
- other problems related to cold (e.g. insufficient lighting, varying thermal environments, varying workload)

The results of the questionnaire are summarized in a table and evaluated on the basis of the score and corrective actions suggested. On the basis of the observed problems, management measures should be taken to eliminate or reduce the source of harm. A further analysis should be conducted if the problem at work cannot be easily reduced or eliminated, or whenever it is uncertain whether the preventive actions have been sufficient to guarantee worker health and safety.

<u>The use and advantages of the cold-risk checklist</u> (Risikko, 2009):

- inexpensive, does not require specific expert knowledge
- cold risk should be identified and analyzed when outdoor cold work is to be done
- can be utilized in conjunction with general risk assessment and/or regular occupational safety check at the workplace
- if personnel at the workplace cannot solve the problem – level II - analysis should be performed– more detailed assessment of cold risk

<u>When should the checklist be utilized ?</u>

- a few times during the winter (once a month and/or if environmental conditions change)
- when the nature of the work alters substantially
- when the work environment alters substantially
- after new preventive measures have been introduced.

From a management point of view, HSE personnel should give a briefing on how to use the checklist and also consider the worst-case scenario. The methodology presented in ISO 15743 could be implemented as part of the job hazard analysis (JHA) described in NORSOK S-002, Clause 4.4.3.

Quantification of cold effects - measurements/analysis (stage 2):
In stage two, tools for further analysis of cold-related problems, quantifying, analyzing and estimating the cold-related effects are presented, and we recommend that occupational health care or safety professionals should conduct the analysis. Based on the estimated cold risk in stage two, appropriate cold risk management measure should be introduced. If it is still uncertain as to whether the management methods are adequate to ensure the worker's health and safety, a further analysis should be performed.

<u>Stage 2 analysis should at least include (modified from ISO 15743):</u>

- follow up the stage one checklist, focus on identified problems
- allow a decision about specialist assessment to be made
- analysis of cold-related problems according to ISO 150743 (2008) Annex B
- tissue cooling: superficial frostbite - WCI (ISO 11079:2007)
- required clothing, need for warming up : IREQ (ISO 11079:2007)
- cold surfaces (ISO 13732:2005)
- contact with water, liquids, moist materials
- protective clothing
- protection of hands, feet and head
- finger and hand dexterity assessment
- distraction:
    - cooling effect on arousal, vigilance and concentration
    - superficial discomfort that could cause distraction
    - cold feet – distraction and risk of slipping
- identify cost -effective solutions

Generally speaking, the risk of cold can be divided into *whole-body cooling* and *local cooling* (Holmer, 2009). As described in detail earlier, ISO 11079 provides a methodology for assessing whole-body cooling and estimates the clothing insulation required (IREQ) for preserving heat balance at defined levels of physiological strain (see chapter 14 and 15 for further description and use of the IREQ model). ISO 8996 (2004) provides a methodology for determination of metabolic heat production and tables that can be used, depending on the type of work involved. ISO 9886 (2004) describes methods for measuring and interpreting the following physiological parameters: body core temperature, skin temperatures, heart rate and body-mass loss.

Local cooling of hands and feet are frequently observed during work in the cold. Protection of extremities is dependent on the heat transported to the peripheral circulation and the insulation in gloves and footwear (Kuklane, 2009). Frequent control of finger temperatures is recommended and ISO 11079 recommends that finger temperatures should be higher than 24 °C for preservation of good hand function. Occasionally, finger temperatures down to 15 °C may be acceptable, but dexterity, strength and coordination suffer, and persons may complain of pain (Holmer, 2009). Hand and finger temperature may seriously drop when touching or gripping cold materials. As described earlier, ISO 13732 (part 3) provides information about surface temperatures of a range of materials that may be touched. The standard provides criteria for the evaluation; pain sensation, numbness and frostbite. Numbness in the cold is associated with sensory deprivation. If finger and hand function is severely impaired, the risk of accidents and injury is greatly increased (Holmer, 2009).
Protection of hands and fingers is provided by gloves or mittens. European standard EN 511 describes two types of insulation to be measured: insulation against convective cooling (whole glove) and insulation against contact cooling (palm of glove). Tested gloves are assigned to any of four classes depending on test results; the higher the class, the better protection.

Specialized measurements - complex cases - expert evaluation (stage 3)
A specialist should be contacted when problems need to be quantified as a basis for selection of appropriate and cost-effective preventive measures. Only for very complex problems and for the construction of a company risk management program will technical and medical experts need to be called (ISO 15743). Many of the specific problems of cold stress can be assessed by the international standards described above. If problems not covered by standards, for example work under changing work conditions, snowy and icy conditions, and use of special protective equipment, an expert may be called in to set up a complete management programme for cold-related risk factors.

17.2.2 Cold risk management

ISO 15743 provides a methodology that describes how the practices and methods of cold-risk assessment should be implemented in the occupational health and safety management system of the organization. Workers, foremen and safety delegates as well as occupational health care professionals should be trained to identify, assess and manage cold-related risks at work. Risikko (2009) developed a systematic model for evaluation and managing cold-related health and safety risks that was later adopted by ISO 15743. An overview of the model is provided in Figure 12:

The usability of standards for cold risk assessment and management in the workplace has been evaluated in practical use at workplaces (Makinen and Hassi, 2002). Persons who were unfamiliar with the methods described in the ISO standards performed the risk assessment according to ISO 15743. The study showed that the usability of the methods at stage 1 was regarded as easy to adopt, the duration of the assessment was short (average 30 min), and the results were easy to analyze. The methods of stage 2 were found to be more laborious, required more training and took longer to complete (Makinen et al., 2002). Additional instructions were often requested, especially when analyzing the results.

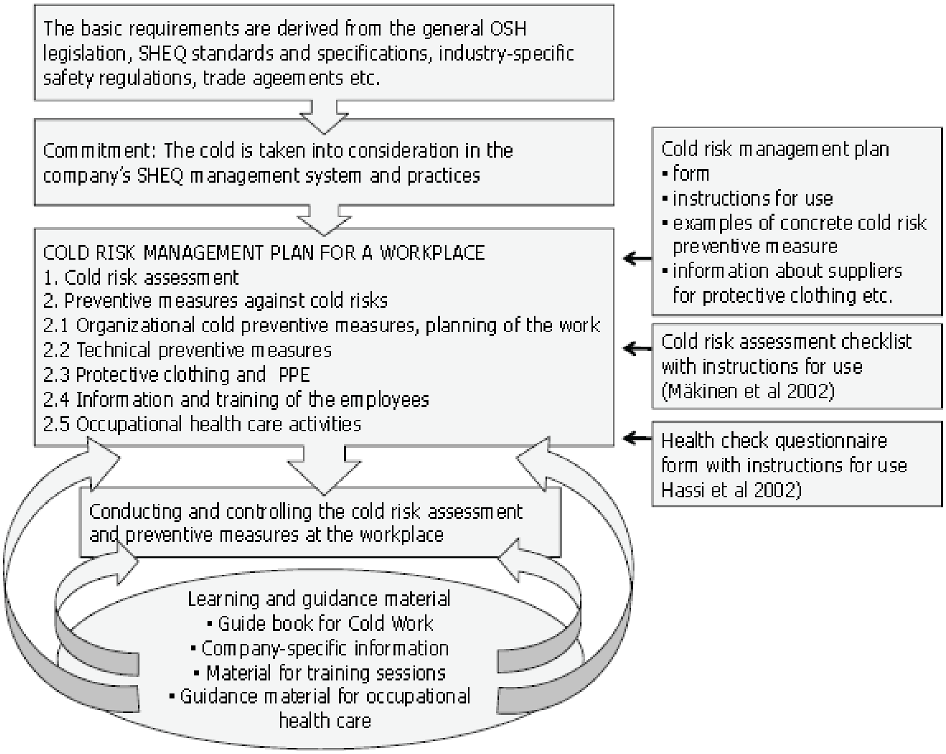

Figure 12 Cold Risk Management Model and related methods. From (Risikko, 2009)

17.2.3 **Health risk assessment in the cold**

A cold risk management system should also include a plan for health assessment in the cold. ISO 15743 provides a method for health assessment that follows the same three-stage logical framework as the cold risk assessment, while ISO 12894(2001) provide guidelines for medical supervision of individuals exposed to extreme hot or cold environments. Health assessment method is further described in Chapter18 in this report.

17.3 Recommendations for cold risk assessment and management

- It is recommended to use the occupational cold-risk assessment and management model provided in ISO 15743 as this includes both organizational and technical measures in work-place. This is in line with the recommendations from the Barents 2020 report (2012).
- It is further recommended that the cold risk model and practices presented in ISO 15743 should be integrated into the occupational health and safety management system of the company.
- The model should be adapted to the risk management models, rules and regulations currently in use by the petroleum industry.

A suggestion for how to implement the ISO 15743 is given it the following paragraph.

17.4 Guideline for cold risk assessment and management

17.4.1 Cold risk assessment

Design stage – decide on cold risk preconditions

Definition of the climatic zones
We recommend using the climatic zones of the Arctic, as well-defined by the Arctic and Antarctic Research Institute (AARI) of St. Petersburg (see chapter 12).

Environmental and cold climate preconditions
Appropriate physical environmental design parameters and methodologies to design, analyse and assess arctic and cold region structures are given in ISO 19900. General guidelines on MetOcean information are given in ISO 19900 and specific requirements in ISO 19901-1. An overview of sources of MetOcean data is given in Chapter 12 of this report:

Met-Ocean data (wind, air temperature, visibility, precipitation, and snow and ice conditions) should be assessed at the specific geographical location of the installation or where an operation is to be performed. The environmental parameters should be monitored and forecast during the design phase in accordance with ISO 19906:2010 and ISO 19901-1. MetOcean data should be used as the basis for winterization. As variations between years occur, we recommend specifying meteorological data as annual mean of the most recent five years. In addition wind chill temperature (WCT) calculations for the three coldest months should be done. Estimates should be made both for the extreme (maximum) and mean values of combinations of temperature and wind. The WCT should then be calculated as described in the equitation in ISO/TR 11079, Annex D.

Design considerations
Designer should take into account all relevant issues and associated parameters for each scenario considered (not only the meteorological data), including human factors, e.g. cold stress, darkness, illumination, isolation etc.

Operational stage – cold risk assessment
In the design stage, the operating environment is identified on the basis of the Met-Ocean data.

NORSOK S-002, Annex A-Working environment area limits, 6.1.0-1 defines the most exposed open work areas outdoors as external walkways and access ways, muster area, general process and utility area, drill floor, monkey board, pipe-rack area, mud room, blowout preventer and well-head.

These areas and all open and semi-open work areas should be defined as critical for cold exposure, and cold risk assessment should be performed.
It is recommended to use the stepwise model from ISO 15743 for identification of cold risk. Level 1 is based on observations, and do not require comprehensive training or knowledge in physiology or ergonomics. Figure 13 provides an overview of the 3 stage model of cold risk assessment.

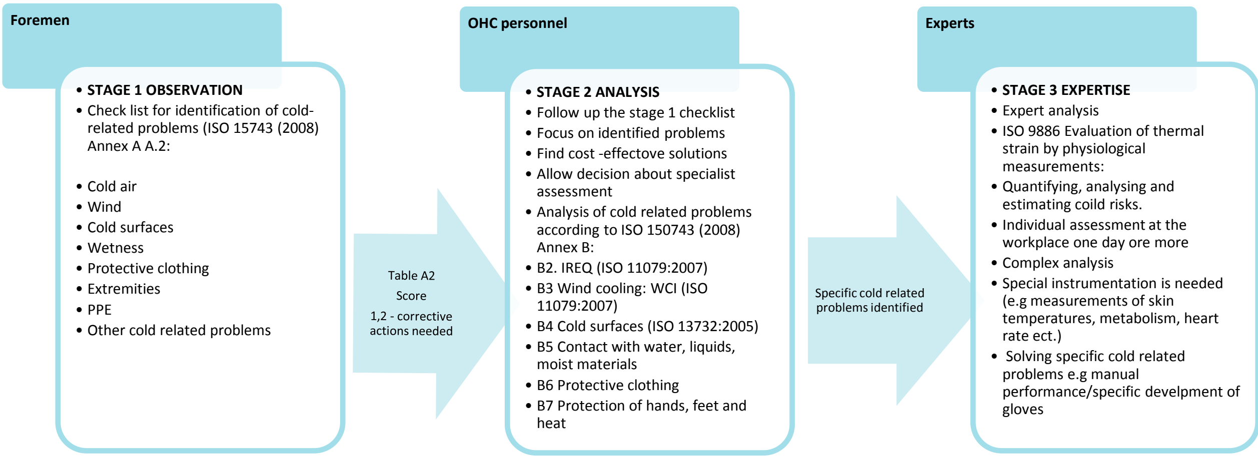

Figure 13 ISO 15743 Cold risk assessment – three-stage model.

STAGE 1 OBSERVATION

The checklist A.2 in ISO 15743:2008 is recommended for early identification of potential cold- related problems. Special attention should be paid to manual tasks, handling of tools and equipment, icing and falling ice, snow drift, darkness and lighting.

This checklist should be implemented as part of the Job Hazard Analysis (JHA) described in NORSOK S-002 Clause 4.4.3. The additional potential job hazards/risk of occupational injury stemming from exposure to Arctic environmental factors should be identified. These include exposure to cold air and surfaces, icing and falling ice, wind and precipitation, snow drift, darkness and brightness, glare from low-angle sunlight, etc.

Arctic installations may be designed with enclosed, semi-enclosed or sheltered topsides to protect operators and operations from the cold weather. The possible indirect effects of reduced ventilation and increased vapor, particle or gas exposure and explosion risk should be considered in the Job Hazard Analysis for such areas.

<u>When to perform stage 1 observation:</u>

- a few times during the winter (once a month and/or if environmental conditions change)
- when the nature of the work alters substantially
- when the work environment alters substantially
- after new preventive measures have been introduced.

STAGE 2 OUTDOOR WORKING ENVIRONMENT ANALYSES

Based on the checklist identified in stage 1, an outdoor operation analysis should be carried out for the open and semi-open areas where corrective actions are needed. In the analysis it is important to focus on identified problems in stage 1 and select the appropriate preventive assessment method for the problem. The analysis should include; identification of tasks, types of work to be carried out, duration, physical workload and urgency with respect to safe and reliable operations.

In order to identify and remedy potential problem areas due to overall exposure to temperature, wind, icing and precipitation, including investigation of the weather protection necessary to comply with WCI and other functional requirements identified in the analysis. This set of outdoor working operations analysis should be performed in accordance with the procedures described in ISO 150743: 2008, Annex B (Figure 13):

- IREQ (ISO 11079:2007)
- Wind cooling: WCI (ISO 11079:2007)
- Cold surfaces (ISO 13732:2005)
- Contact with water, liquids, moist materials
- Protective clothing
- Protection of hands, feet and heat.

See chapter 15 for recommendations and guidelines for required protection related to work intensity, risk of frostbite, contact cooling and duration of cold exposure on the basis of the WCI and IREQ model.

<u>When to perform stage 2 cold risk assessment:</u>
Whenever any of the check points in stage 1 have shown serious problems

- Ambient conditions change considerably
- Work tasks change considerably

STAGE 3 only applies when very complex cold related problems are identified and when technical and/or medical experts are needed.

17.4.2 **Cold risk management**

Employers are to determine whether cold-related hazards are significant and should control significant hazards by means of elimination, isolation (where elimination is not possible or practicable), minimization, where isolation is not possible or practicable.
The recommendations for management system of cold risk are based on ISO 15743 (Figure 14). This system should be implemented in the general risk management plans of the employer. For example it could be implemented as part of the general method for management of working environment health risk described in WEHRA, Statoil Internal Document (2010). A suggestion of modified version of the Concept Work Environment (WE) impact assessment in cold environments is provided in Appendix D.

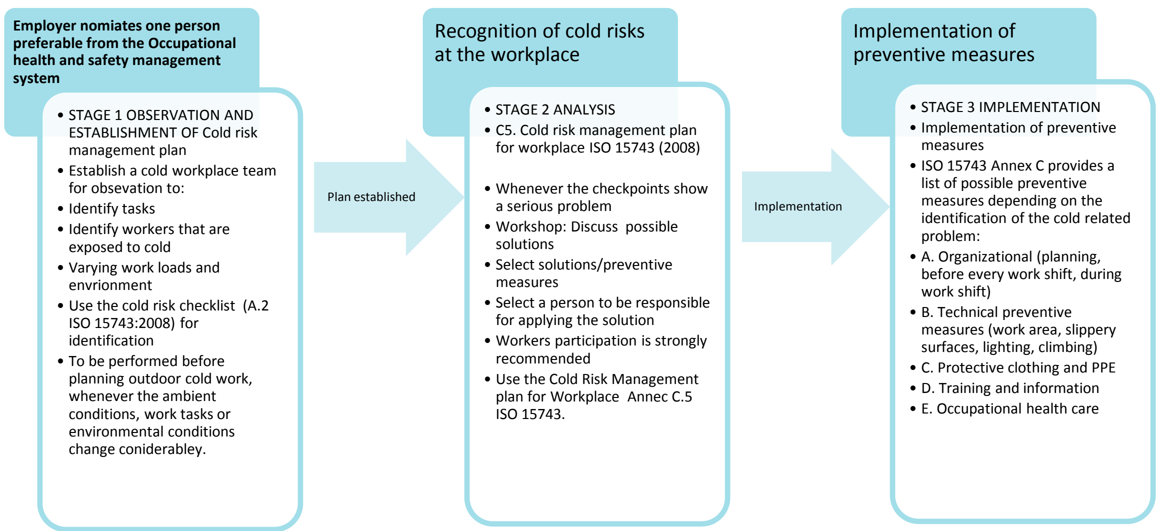

Figure 14 Cold risk management system.

Organizational injury prevention consists of appropriate planning of activities, adjusting scheduling to expected weather conditions, and the possibility of providing safe and warm shelters close to the workplace.

It is recommended to:

- Establish a cold workplace team that should be responsible for the design and implementation stages and for continuous follow-up of cold-related issues.
- The management system should consider human factors such as experience, training, night-time operations (year-round in some cases), etc.
- For new operations, temporarily reduced performance should be considered, in the expectation that performance will improve.
- Achievement targets should be established and seasonal evaluations of performance should be carried out.
- A cold-risk management plan should be developed as a part of the general occupational safety plan of the individual workplace (this depends on the circumstances – offshore/land based etc), the plan should at a minimum include (Hassi et al., 2001b):

1. Cold-risk assessment checklist
2. Organizational cold protective measures
    a. Duration and intensity of exposure
    b. Time for recovery
    c. Extra manpower
    d. Planning of some activities to the summer
    e. Monitoring system (buddy system/WCI)
3. Technical preventive measures
    a. Shelter
    b. Tools and machinery
    c. Reduction of slippery areas
    d. Lighting
    e. Insulation of work area
4. Protective clothing and PPE
    a. Need for thermal insulation (IREQ)
    b. Clothing for cold and foul weather (EN 342)
    c. Compatibility
    d. Hand, foot, head, face protection
5. Information and training
6. Occupational health care

EN 342:2004 This European Standard specifies requirements and test methods for performance of clothing ensembles (i.e. two piece suits or coveralls) and of single garments for protection against cold environment. It does not include specific requirements for head wear, footwear and gloves intended to prevent local cooling

17.4.3 Health risk assessment for work in cold climates

The management of cold related risks should also include health risk assessment for work in cold climate (Figure 15). The recommendations for health risk assessment for work in cold climate are based on ISO 15743 and ISO 12894.

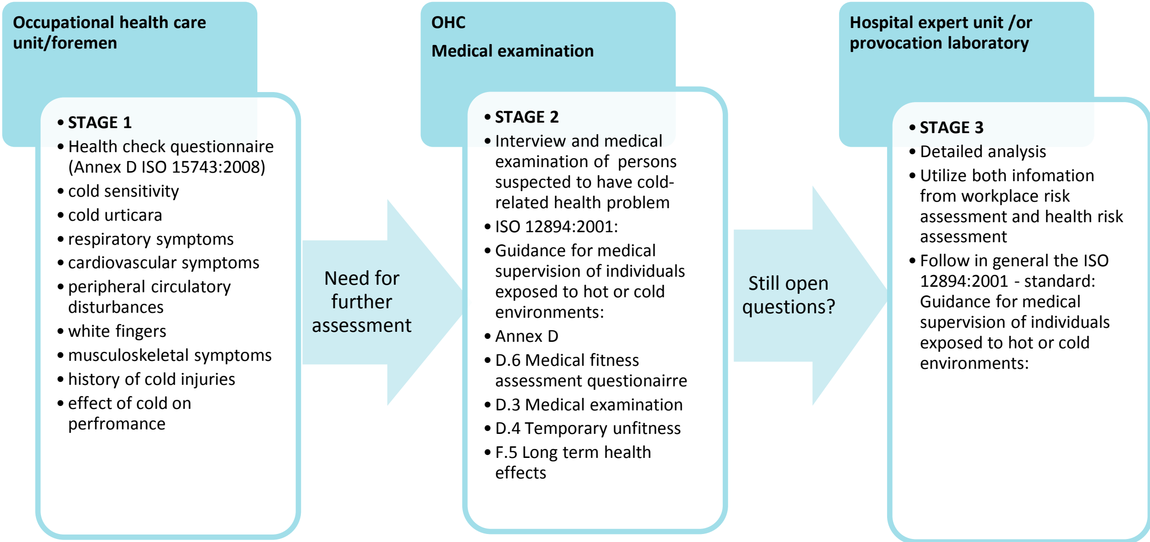

Figure 15 Cold risk health assessment.

The health check list for cold work can be used to identify cold-related health aspects. Also other occupational health factors related to cold climate should be considered, including:

- physical and chemical factors
- ergonomic factors
- psychosocial factors
- individual health and performance – reaction to specific work conditions: isolation, low temperatures, darkness, organisation of work, noise and vibration
- personal factors : age, gender, place of residence, ethnicity, personality characteristics)
- work organization: shift work, exercise

The general recommendation and guidelines for assessing these factors are already given in TR 0926 2012-03-05 (Internal Statoil document) , and can be used also for assessing additional risk associated with cold climate.

Health aspects and recommendations for health exclusion criteria's is described in detail in chapter 19.

18 Monitoring systems for outdoor work in the cold

Objective: To provide suggestions for a monitoring system for objective assessment of the outdoor thermal situation in critical work areas. This should include suitably adapted climate monitoring of critical work areas.

According to NORSOK S-002, 4.4.9 Outdoor operations/cold stress:

"*Outdoor operations analyses shall be carried out for open work areas and semi-open work areas, in order to identify and remedy potential problem areas due to overall exposure to temperature, wind, icing and precipitation, including investigation of the weather protection necessary to comply with WCI and other functional requirements identified in the analysis*".

NORSOK S-002, Annex A-Working environment area limits, 6.1.0-1 identifies the most exposed outdoor work areas as external walkways and access ways, muster area, general process and utility area, drill floor, monkey board, pipe-rack area, mud-room, blowout preventer and well-head. These areas and all open and semi-open areas should be defined as critical work areas for cold exposure, and objective temperatures and wind speeds should be monitored in these areas.

18.1 Workplace monitoring

Continuous monitoring of environmental parameters such as air temperature, relative humidity and wind speed at the work-site provides the control-measure data required to manage work in extreme temperatures. Monitoring environmental data can be integrated into existing information management systems. Real-time information about the WCT at the work site can be communicated to a control room and/or provide visual updates of temperature and wind conditions at the worksite. The monitored data can provide direct information about the risk indicators from the WCI tables. The WCT information could be displayed at the work-site in the form of colour risk codes (see Table 6). This could be a way of controlling the individual work environment when performing specific tasks. The system should not be used as a substitute for, but rather in addition to, a buddy monitoring system.

18.1.1 Smart jacket for physiological and environmental monitoring

The WCI assesses the risk of freezing of the unprotected human skin. The IREQ model provides recommendation on required clothing insulation and exposure times in the cold. However, we currently lack a standard that would provide easily accessible information about the thermal conditions at the work-site or local cooling of finger and hands. A wide variety of specialized equipment for physiological monitoring system exists and is used by physiologists in field studies. Recent developments in smart textiles with integrated electronics have revealed new opportunities for personal monitoring systems integrated into clothing. Such systems include monitoring of heart rate, ECG, body temperature, positioning, vibration and skin temperatures, for example of the hands in the cold. Knowledge of the physiological responses of workers can provide more exact information about the critical temperature limits for safe performance in cold environments.

A recently published study by Seeberg et al (2013) demonstrated that sensors can be integrated into offshore workers' jackets. The demonstrator jacket provides valuable information about the ambient conditions and local cooling effects of extremities at the site of the worker during high- and low-intensity work in cold and warm environments, without disturbing the user. The jacket includes an encapsulated sensor module with integrated sensor system (IsenseU) and vacuum-moulded humidity and temperature sensors connected to flexible wires. The data are transferred via Bluetooth Smart to the worker's own mobile phone or command central (Figure 16). IsenseU has been verified in the lab for wireless communication, battery capacity and splash protection. A validation study demonstrated a clear relationship between the reference temperature at the hands and IsenseU skin-temperature measurements that can be used in the future as a tool to provide early warnings of critical temperature limits for manual performance. The humidity sensor might be an indicator of perspiration. The demonstrator is capable of distinguishing between activity and rest and more sophisticated sensor fusion algorithms might be incorporated to assess work-load and activity level. All this information can be used in an enhanced safety perspective and as an improved tool to advise outdoor work control for workers in cold climate, and thus representing an improvement over existing international standards.

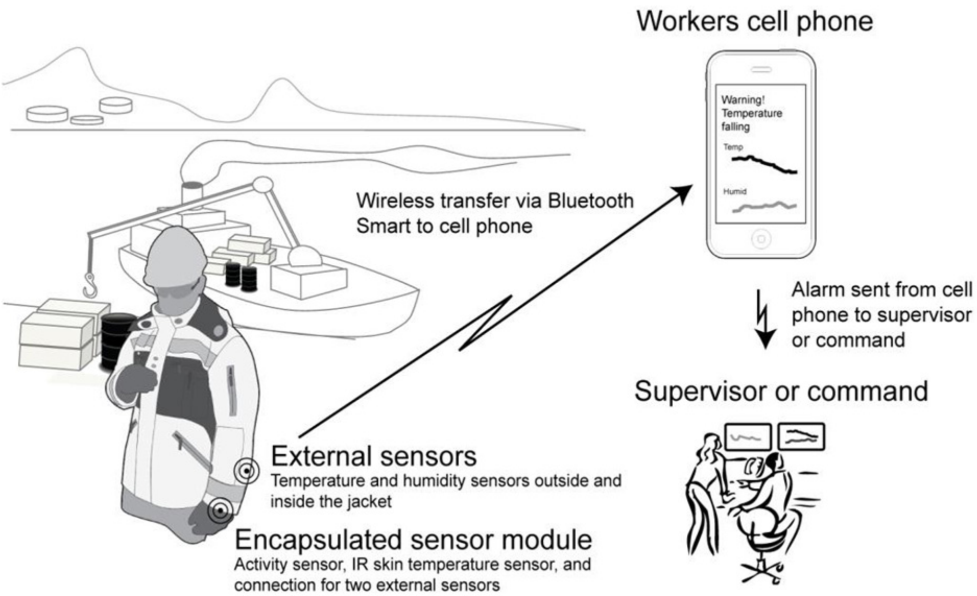

Figure 16 Personal monitoring system (Ill. Tore Christian Storholmen)

System possibilities:

- Measure physiological parameters on the worker
    - Activity level
    - Skin temperature of hands/fingers (to predict reduced manual performance)
    - Measure temperature/ humidity inside the jacket (to indicate general thermal comfort/sweat)
- Measure ambient conditions (humidity/temperature) at the work-site
- Communicate measured parameters wirelessly to an external supervisor/command for evaluation/decision support
- Preliminary studies indicate that the unit can be used to assess vibration exposure from the use of handheld tools or similar

18.2 Recommendations for monitoring system

To avoid the risk of frostbite, we recommend implementing a system of continuous environmental monitoring of all open and semi-open areas of the platform/installation where workers are expected to be exposed to WCT below -10 °C and the duration of outdoor activity is expected to exceed 40 minutes. These areas should be identified in the design stage of the planning and risk assessment of cold exposure.

19 Health exclusion criteria

Objective
How can we incorporate the fact that different people react differently to cold stress (earlier frost injury, diabetes etc.). Recommend health exclusion criteria.

19.1 Effects of cold exposure on health

Different groups of people react differently to cold stress. This includes differences between young and elderly, males and females, people of different ethnicities and workers who perform a variety of tasks that expose them to cold of different degrees of severity (see section I). In addition, people with diseases such as asthma, diabetes and earlier frost injuries may experience a worsening of their diseases as a result of exposure to cold.

Cold-related diseases are defined as diseases which are either caused by cold or whose symptoms are aggravated during cold exposure. These thus include many of the most common chronic diseases like respiratory and cardiovascular diseases. The worsening of symptoms of musculoskeletal diseases has also been commonly reported in association with cold work (Raatikka et al., 2007). Cold exposure has also been shown to involve a variety of complaints ranging from subjective uncomfortable sensations to symptoms related to diseases (Sandsund et al., 2001, Makinen and Hassi, 2009).

Cold exposure may be a triggering factor for certain diseases and aggravate the symptoms of prevailing chronic diseases. Persons suffering from a chronic disease have increased sensitivity to cold. Therefore, occupational exposure to cold increases the manifestation of the symptoms of the underlying disease. Such persons may therefore experience performance decrements and health problems at an earlier stage than healthy employees. In individuals who are especially susceptible to cold exposure, certain 'hyperreactions' to cold may occur. These include for example an exaggerated constriction of blood vessels in the hands (Raynaud's phenomenon), internal organs (e.g. kidney, lung, heart) or eyes due to cold exposure. Tissue cooling may also provoke cold urticaria. These reactions may lead to various types of functional disturbances of various degrees of severity. Furthermore, persons with different cold symptoms are also very sensitive to cold discomfort (Makinen and Hassi, 2009).

The results of a study of cold risk in 130 subjects from the fishing industry in Norway (n=52) and construction (n=68) and maintenance (n=10) in Finland are shown in Figure 17 (Hassi et al., 2001a). The results show the presence of various cold-related symptoms in employees.

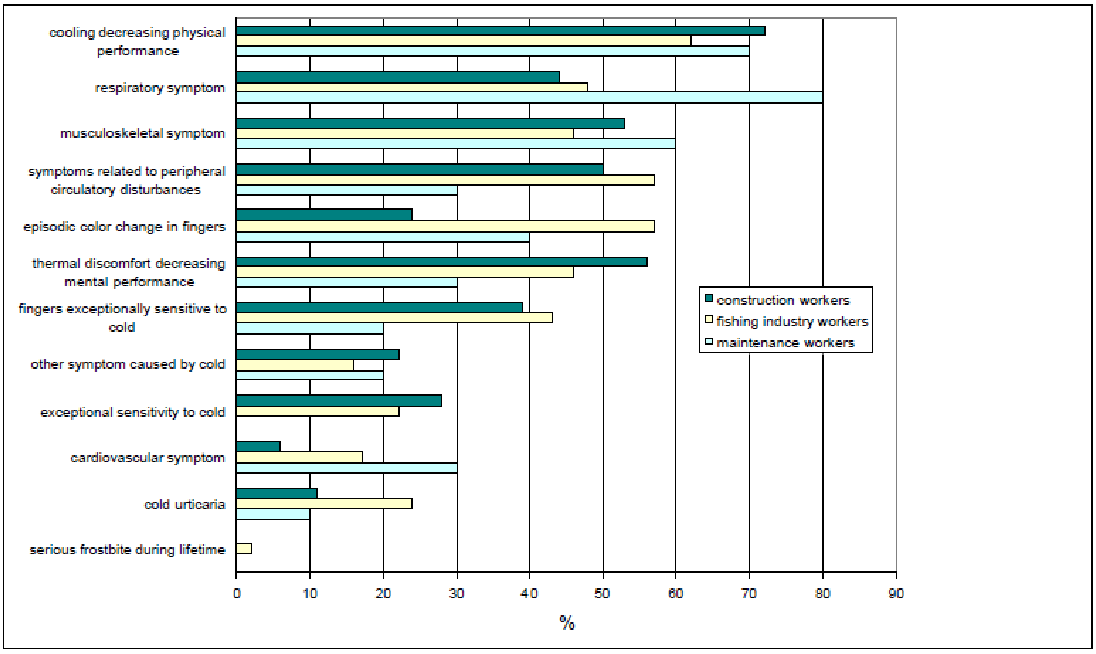

Figure 17 Cold related health effects and symptoms in different industries in Finland and Norway (Hassi et al, 2001).

The major health effects of occupational exposure to cold on human health were systematically presented by Mäkinen and Hassi (2009) and are shown in Figure 18. An *illness* is defined as a state where physical, mental or social well-being are not complete, and is often a subjective estimate. A *disease* is limited to a doctor-diagnosed condition. Symptoms and complaints are manifestations of an illness or disease (Makinen and Hassi, 2009).

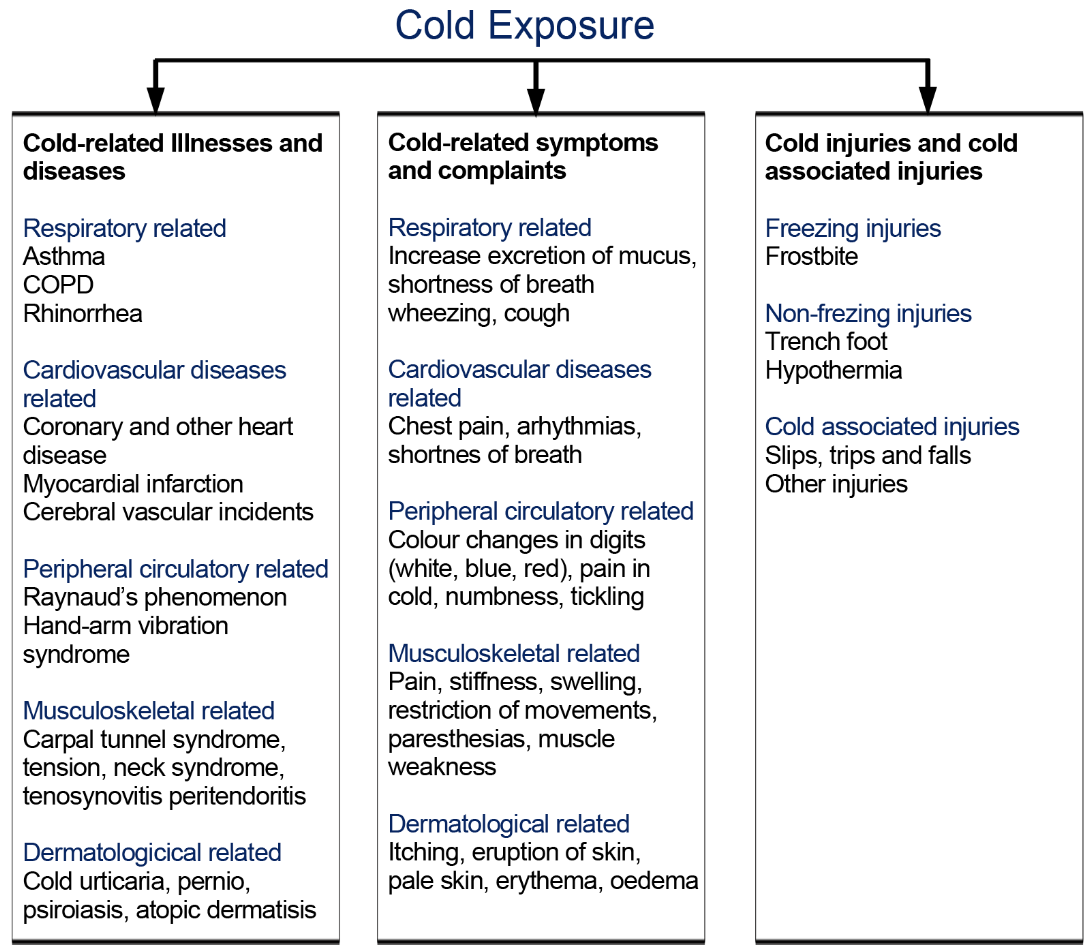

Figure 18 The effects of occupational exposure to cold on human health (From Mäkinen and Hassi, 2009)

19.2 Cold-related illnesses and diseases

This section describes different diseases that commonly occur in cold environments. Description of diseases from ISO 12894:2001 are followed by the results of the literature study.

Respiratory related

Cold air inhalation may precipitate an asthmatic episode. This is particularly likely to occur in association with exercise levels which are moderate or high. Asthmatics may know whether or not their disease is provoked by cold exposure or exercise. Cold air inhalation can also provoke coughs, rhinitis and nose bleeds and care should be taken with individuals already suffering from these conditions (ISO 12894:2001. Annex D B.4.2 and D.3.3). A chronic obstructive pulmonary disease (esquimo lung) has been reported in the residents of sub-arctic regions, but it is not known whether this condition is solely attributable to cold air inhalation (ISO 12894:2001. Annex D – B.4.2.).

The prevalence of bronchial asthma in most western countries is reported to be between 5 and 10% of the population (Pekkanen et al., 2005). The occurrence of respiratory symptoms increases with age and is more common in females. Respiratory problems are generally more common during exercise that involves increased ventilation of cold and dry air (Koskela, 2007). Respiratory symptoms and pulmonary obstruction triggered by cold exposure may lead to a decrease in working capacity in the cold. Especially in subjects with an obstructive respiratory disease (asthma, chronic obstructive pulmonary disease - COPD) symptom are worsened in the cold and may lead to a decline in work capacity (Makinen and Hassi, 2009).

According to Koskela (2007) cold air is unlikely to be a causal factor of respiratory diseases but may be a symptom trigger. The short-term responses are those that develop within minutes in response to sudden cooling of the airways. Subjects with asthma or rhinitis are especially prone to these responses. The long-term responses are those that develop in response to repeated and long-standing cooling and drying of the airways, usually in endurance athletes. Finally, there are the physiological, reflex-mediated lower-airway responses to cooling of the skin or upper airways.

Living and working in a cold climate

Population-based studies have shown that living and working in a northern environment increases the number of respiratory complaints. A large epidemiological study (over 12,000 participants) in a northern climate revealed that respiratory symptoms (wheezing, tightness of breath, cough, sputum) were more prevalent in the north, and the highest prevalence of COPD and its symptoms was detected among outdoor workers, especially among smokers (Kotaniemi et al., 2003). Another epidemiological questionnaire study (n=7,937) examined respiratory symptoms and obstructive pulmonary diseases experienced during exercise, and found that the risk of shortness of breath and chronic bronchitis during exercise in cold weather was higher in outdoor than indoor workers (Kotaniemi et al., 2003).

Relatively few reports have addressed cold working conditions and respiratory health, and these are limited to special occupational groups. Studies of healthy athletes have reported that repeated chronic hyperventilation of cold dry air in cross-country skiers for several years can induce permanent bronchial disorders and induce ventilator limitations during intense exercise (Verges et al., 2004).

Recommendations for lowest temperatures of inspired air are given in ISO 11079 Annex B. At ambient temperatures below -15°C, respiratory protection is recommended for high activity levels (with increased ventilation volume). At ambient temperatures below -30°C, respiratory protection is strongly recommended (ISO 11079 Annex B.3).

Cardiovascular related

Cold exposure causes physiological effects which may be harmful to those with cardiovascular disease. These include the induction of bradycardia and hypertension. Cold air inhalation may precipitate attacks of angina pectoris. Individuals suffering from ischaemic heart disease and/or hypertension are at risk in extreme cold. Vasoconstriction of peripheral tissues is the normal response to cold exposure. This may be problematic in the presence of peripheral vascular disease. Raynaud's phenomenon may be triggered in susceptible individuals and repeated exposures may be unwise (ISO 12894:2001. Annex D - D.3.2).

A population study has shown that cardiovascular symptoms such as arrhythmias and chest pain are experienced in the cold by about 4% of the general population (Raatikka et al., 2007). Cold exposure contributes to increased cardiovascular morbidity and mortality (Mercer, 2003, Näyhä, 2005). Deaths from myocardial infarcts and coronary heart disease occur more frequently during the winter (Näyhä, 2005). Mortality from congestive heart failure also increases linearly with cold temperatures, with a lag of two days after a cold spell (Kolb et al., 2007).

Cardiac function during exercise in the cold

The cardiac load is higher in the cold due to cooling induced vasoconstriction, that increases the peripheral resistance and central blood volume. Furthermore, cardiac filling pressure, left ventricular end-diastolic pressure and volume, and stroke volume are increased (Vuori, 1987). Cold exposure is strenuous for the heart and the increased workload may be further aggravated by exercise in cold. Work in the cold can be even more strenuous for patients suffering from a cardiovascular disease than for healthy persons.

According to Mäkinen and Hassi (2009), there are no studies which examine cardiovascular problems with a special emphasis on cold work. They refer to a review of the epidemiological studies concerning cardiovascular risk factors and the work environment that indicated that "Heat and cold appear to have an acute effect on the incidence of cardiovascular diseases, but the possible chronic effect has seldom been investigated" (Kristensen, 1989).

Hypertension and cold work

Experimental studies suggest that cold exposure raises systolic and diastolic blood pressure in healthy subjects by 7–26 mmHg (Emmett, 1995, Korhonen, 2006). The increase in blood pressure in the cold is dependent on several factors, such as the intensity and type of cooling (whole-body, local, water, air), as well as individual factors. The type of cooling on cardiovascular responses is important, and a sudden local exposure to severe cold (e.g. local cold-water immersion) is more stressful than a long-lasting, milder whole-body exposure to cold (Korhonen, 2006). Elevated blood pressure is one of the most important risk factors for cardiovascular events, and the risk of hypertension may be increased by long-term exposure to cold (Mitchell et al., 2002). On the other hand, cold temperatures exacerbate hypertension in hypertensive patients (Fujiwara et al., 1995). For example, mildly hypertensive patients displayed increased blood pressure during the cold season, an effect that increased with age (Brennan et al., 1982). Repeated exposure to cold at work may also increase the risk of hypertension.

Peripheral circulatory related

Raynaud's phenomenon (RP)
RP is a common clinical disorder manifested by recurrent vasospasm of the fingers and toes, often associated with exposure to low temperatures or emotional stress (Lally, 1992). The aggravated vasoconstriction in response to cooling can result in decreased performance in persons with RP. Patients with primary RP show an altered cold-induced vasodilatation (Jobe et al., 1985) and a delayed recovery of blood flow after cooling (O'Reilly et al., 1992). This indicates an impaired thermoregulation in RP patients (Greenstein et al., 1995).

Hand-arm vibration syndrome (HAV)
Exposure to hand-transmitted vibration may cause a variety of disorders collectively known as the Hand-arm vibration syndrome (HAV). Its neurovascular component is vibration-induced white finger (VWF), which is a secondary form of RP occurring in professional users of vibratory tools or machines. It is characterized by episodes of finger blanching attacks often triggered by exposure to cold. Thermal sensitivity to cold may also be impaired (Nilsson et al., 2008). Workers suffering from HAV symptoms may experience greater difficulties while working in cold environments. Concerning the treatment of RP several pharmacological treatments have been reported, but there is still no cure or gold standard for optimal outcome (Bakst et al., 2008).

Metabolic disorders
Normal thermoregulation in the cold will be impaired in the presence of untreated thyroid disease and may be impaired in diabetes mellitus. Care should be taken with individuals who suffer from these, or other, metabolic disorders (ISO 12894:2001. Annex D – D.3.4).

Diabetes is associated with metabolic disturbances, which may affect thermoregulation and increase the risk of cooling. The disease is also commonly associated with peripheral neuro- and vasculopathies, which alter the ability to regulate heat loss in the extremities. For instance, the vasoconstriction response to local cooling is impaired in diabetics compared with healthy subjects (Stansberry et al., 1997). Research results concerning the association between diabetes and cold exposure are scarce, and reports on diabetics in an occupational context in particular are lacking.

Musculoskeletal disorders
Cooling reduces the power which muscles is able to generate and may impair joint movement in the presence of arthritis (ISO 12894:2001. Annex D – D.3.5).

In a population study by Raatikka et al (2007), musculoskeletal symptoms, such as musculoskeletal pain, were the most common complaints (27–30%) reported to occur during the winter (air temperature defined at 10°C or below).

Cold indoor work
Several reports describe the association between musculoskeletal symptoms and cold in the food industry. In a questionnaire study (n=1,117) that assessed the prevalence of musculoskeletal symptoms in food-processing facilities (most of the respondents exposed to +1 to +10°C) indicated that ageing and female gender were associated with a greater incidence of musculoskeletal symptoms. In addition, factors related to the workplace (draught, cooling and prolonged exposure to cold) were thought to increase musculoskeletal symptoms (Sormunen et al., 2009).
The intensity of cold exposure seems to be at least partially related to musculoskeletal symptoms and complaints. A sensation of cold, which is often related to adverse local or whole-body cooling, is also associated with musculoskeletal complaints. For example, industrial workers (n=1,767) in the seafood industry (measured air temp +2 to +18°C), who reported that they often felt cold, had a significantly greater prevalence of symptoms from muscles, skin, and airways, than those who never felt cold at work (Bang et al., 2005). A proportion of musculoskeletal complaints in cold indoor work may be due to the combined effects of cold exposure and repetitive work.

Cold outdoor work
Reports of musculoskeletal symptoms caused by cold outdoor work are fewer than those due to indoor work (Makinen and Hassi, 2009). An epidemiological questionnaire study of workers (n=2,030) from 24 different occupations concluded that climatic factors were related to low-back and neck-shoulder symptoms and sick leave due to neck-shoulder symptoms (Hildebrandt et al., 2002). Draughts in particular were related to neck-shoulder symptoms, which were also inversely related to frequent outdoor work. Approximately 25% considered that their musculoskeletal symptoms were related to climatic factors (Hildebrandt et al., 2002).

Most of the reports concerning musculoskeletal symptoms and complaints at work are derived from cold indoor work (Piedrahita, 2008, Pienimäki, 2002). Although scientific evidence suggests that there is an association between cold exposure and musculoskeletal complaints, there are methodological limitations in many of the epidemiological studies that do not allow a causal relationship to be identified (Piedrahita, 2008, Pienimäki, 2002). Musculoskeletal problems seem to be associated with work in the cold. However, longitudinal studies and studies involving cold outdoor work are needed to confirm causality (Makinen and Hassi, 2009).

Skin disorders and diseases
Temperature-dependent skin disorders include erythema, physical urticarias, chilblains, cold panniculitis and cryoglobulinaemias (Page and Shear, 1988). In chronic skin disease the features of the skin are altered, which can increase its susceptibility to cold and result in discomfort, pain, performance degradation, and even injuries. There is little information available on the incidence and prevalence of the common dermatoses, such as atopic dermatitis, psoriasis and acne in cold.

Cold urticaria
Cold urticaria is one of the physical urticarias and represents hypersensitivity to cold with cutaneous swelling, weals and hives after rewarming of skin after cold exposure (Lehmuskallio et al., 1995, Neittaanmäki, 1988). The condition may be life-threatening if large skin areas are exposed to cold (e.g. cold water immersion) and cause an anaphylactic reaction (Siebenhaar et al., 2007). If untreated, cold urticaria may persist for 4-5 years and women are more often affected than men. The best treatment of cold urticaria is to avoid cooling, which is not always possible, however. It is also often treated with antihistamines (Siebenhaar et al., 2007).

Chilblains (Pernio)
Pernio is a vasospastic disorder that affects unprotected skin regions of individuals exposed to non-freezing, damp cold. It is also often categorized as a cold injury (Makinen et al., 2009).

Its pathophysiology is complex and related to patient and environmental factors (AlMahameed and Pinto, 2008). According to Mäkinen and Hassi (2009), little information is available regarding the occurrence of chilblains in an occupational context. Reports from military training have detected cases of chilblains (Makinen et al., 2009, DeGroot and Kenney, 2007).

Skin diseases may limit the possibility of working in the cold. However, studies of the occurrence of skin symptoms and performance in cold work are lacking. Nor do we know what the proportion of persons with skin disease are involved in cold work. However, for all types of activities in the cold, it is important for patients with a skin disease to minimize cooling of the affected skin areas by appropriate cold protection (Makinen and Hassi, 2009).

19.3 Cold injuries and past history of cold illness

Cold injuries are divided into freezing injuries, nonfreezing injuries and hypothermia (Hassi and Makinen, 2000).

Freezing injuries

Frostnip/frostbite may occur on contact with cold surfaces or exposure of naked skin to cold winds. Frostnip is seen as a white spot on the exposed tissues. If not rewarmed it may progress to frostbite, in which the appearance is of an area of marbled white frozen tissue which is cold and firm to touch and anaesthetic. Frostnip and early frostbite can be treated by applying body heat, e.g. from a warm hand to the affected area. In controlled exposures, no more serious injury should arise (ISO 12894:2001. Annex B – B.3.3).

Frostnip is the freezing of skin and superficial tissue (ears, nose, cheek), but not affecting the underlying tissue. Symptoms of frost-nip are pricking pain and skin whitening. Frostbite is the freezing of deeper, as well as superficial tissues. Frostbite is more severe than frost-nip and the various levels of tissue damage are classified from first to third degree. The threshold limit values for exposure to cold conditions by current standards in the petroleum industry are primarily based on the risk of frostbite on bare skin.

Frostbite is a freezing injury where localized damage affects the skin and other tissues. It occurs during occupational or leisure-time activities and is common in the general population among both men and women of all ages (Ikaheimo and Hassi, 2011). A study that analysed cold injuries by examining workers' compensation claims (n=657) and meteorological parameters showed that the rate of injuries began to increase when temperatures fell below –12°C and wind speeds exceeded 4.5 m/s (Sinks et al., 1987). Industries with the highest rates of injury included agriculture, oil and gas extraction, trucking and warehousing, protective services and interurban transportation.

Over 60% of frostbitten persons suffer from sequelae, which have been reported to worsen in the cold environment, and working ability was considered to decrease in 13% even after a moderate cold injury (Ervasti et al., 2000). The adverse effects of the frostbite sequelae may persist for several years after the cold injury. Several factors influence the risk of frostbites. These are environmental (temperature, wind, wetness, cold objects, and altitude), individual (anthropometry, age, sex, race), behavioral (cold adaptation, alcohol use, fatigue, smoking, use of protective ointments, inappropriate or constrictive clothing, prolonged stationary position), and health-related factors (Makinen et al., 2009).

Health related factors such as diabetes, white fingers in the cold, cardiac insufficiency, angina pectoris, stroke and depression increase the risk of frostbite (Makinen et al., 2009). In addition, certain disease states, such as peripheral vascular disease, atherosclerosis, arthritis, Raynaud's phenomena, vibration-induced white finger, hypovolemia, diabetes, vascular injury secondary to trauma or infection, and previous cold-related injuries, may predispose to cold-related injury (Ervasti et al., 2004, Lehmuskallio et al., 1995). Psychiatric disorders are frequently detected among frostbite patients (Hassi and Makinen, 2000).

Vulnerable populations include those suffering from chronic disease (cardiovascular, diabetes, and depression), children and the elderly or homeless people (Ikaheimo and Hassi, 2011). Elderly people have lower heat production capacity (diminished muscle mass) as well as a weakened ability to sense cold (Smolander, 2002, Kenney and Munce, 2003). Elderly persons also often suffer from one or more chronic diseases or use medication that may affect their thermoregulation in the cold. General medications such as β-blockers, sedatives, and neuroleptics may affect thermoregulation and increase the risk of frostbite (Hallam et al., 2010). Several behavioral factors influence the risk of cold-related injuries. Alcohol consumption and smoking increase the occurrence of frostbite (Makinen et al., 2009, Ervasti et al., 2004).

Non-freezing injuries
This condition presents as numbness during exposure and painful swelling of the affected part on rewarming. It is unlikely to occur in controlled occupational exposures due to the long period required for its onset. It may arise, however, after comparatively short periods of immersion of a part in cold water. Injury to a small area, e.g. one finger, may not require any treatment other than painkillers. If large areas are affected, e.g. both feet, treatment is by slow rewarming (ISO 12894:2001. Annex B – B.3.4).

Chilblain is a superficial, mild form of non-freezing cold injury presenting as an area of dark blue/purple discoloration of the skin. This requires no treatment other than possibly pain killers (ISO 12894:2001. Annex B – B.3.5).

Non-freezing cold injuries often occur as a result of prolonged exposure to temperature above freezing and are associated with wet conditions. The most common nonfreezing cold injuries are trench-foot and chilblains (Ikaheimo and Hassi, 2011).

A history of local cold injury may predispose an individual to a subsequent attack at the same site, or another site. A past history of general hypothermia need not indicate a predisposition to this condition (ISO 12894:2001. Annex D – D.3.6).

Pregnancy
There is epidemiological evidence to suggest that women who work in the cold during pregnancy have an elevated risk of miscarriage. It is not recommended that pregnant women should participate in studies of extreme cold environments (ISO 12894:2001. Annex D – D.3.7).

Environmental influences on pregnancy outcome have been observed. Long-term whole body vibration exposures and working in extremely cold environments can contribute to disturbances of pregnancy causing abortion and stillbirth (McDonald et al., 1986).

Drugs and alcohol
Alcohol consumption, either in a single bout, or chronically, has been associated with episodes of hypothermia, and may also impair general health. Acute alcohol and drug abuse may impair thermal tolerance either by direct effects on thermoregulatory mechanisms or by inducing inappropriate behavior (ISO 12894:2001. Annex D – D.3.7).

Other factors that increase risk of cold injuries and frostbite include smoking, alcohol and vasoconstrictive drugs. Vasoconstrictive drugs and smoking reduces blood flow and increases vasoconstriction, and therefore increases susceptibility for low skin temperatures and frost bite in the periphery. Alcohol use often leads to poor judgment and behavioral changes that may not be beneficial in a hostile environment. Prevention measures for avoiding cold injuries and frost bite includes eliminating smoking, alcohol and vasoconstrictive drugs (Auerbach, 2007, Imray et al., 2009, Reamy, 1998).

Psychological factors
The perception of cold on the skin of the face and on the peripheries may be unpleasant. This, coupled with concern about possible cold injury may be a cause of anxiety, particularly for individuals unfamiliar with such exposures (ISO 12894:2001. Annex D – D.3.8).

Medications
Many prescribed drugs and alcohol may impair thermoregulation in the cold. These include antidepressants, tranquilizers, anti-psychotics, hypnotics, drugs of abuse, hypoglycaemics, anti-thyroid drugs, sympathetic and ganglion-blocking agents, vasodilators and calcium antagonists. Tobacco and snuff use will impair peripheral circulation and narcotic drugs also increase the risks in cold environments (ISO 12894:2001. Annex D – D.3.9).

19.4 Regulations regarding health requirements for persons working on installations in petroleum activities offshore

The Norwegian FOR 2010-12-20 nr 1780: "Regulations relating to health requirements for people working on installations in offshore petroleum activities", version 2.1 (01/2012) describes health requirements for persons working on installations in petroleum activities offshore. These requirements are described in more details in: Guidelines to Regulations regarding health requirements for persons working on installations in petroleum activities offshore (Norwegian Directorate of Health. IS-1879.2012):

Section 11: Health requirements
"The person mentioned in section 2 must not, due to his or her health, represent a danger to him or herself or to others or to the safe operation of the installation. The person in question must satisfy the following general health requirements:

- be physically and mentally able to cope with living and working on the installation and with evacuation procedure
- be able to work safely offshore
- not have a condition that could lead to alarms not being registered
- not have a disorder that, due to the lack of essential medication or for other reasons, might seriously endanger to the health and safety of himself or herself or others".

The person in question must also satisfy the following specific health requirements:

1) Vision
Visual acuity must be sufficiently good that the person in question can work in a safe manner on installations in petroleum activities offshore. There must be a normal field of vision in at least one eye.

2) Hearing
Hearing must not be impaired to the extent that acoustic alarms critical for safety and verbal communication may not be perceived.

3) Cardiovascular disease
There must be no cardiovascular disease that might increase the probability of an acute illness requiring treatment.

4) Disturbances to brain function.
There must be no condition that might increase the probability of episodic brain dysfunction or other attacks of reduced consciousness.

5) Mental disorders
There must be no mental disorder or personality disturbance that might lead to impaired judgment, lack of impulse control or behavioral disturbances.

6) Diabetes
There must be no insulin-dependent diabetes mellitus or other antidiabetic medication that might lead to hypoglycemia.

7) Substance abuse
There must be no abuse of alcohol or drugs and no use of tranquilisers or sedatives in doses that reduce alertness and working ability.

8) Lung function
The lung function must be satisfactory.

9) *Mobility*
Sufficient mobility is required for the person to be able to work safely and cope with emergency and evacuation procedures.

10) Use of medication
There must be no use of medication, whether prescribed by a doctor or not, that reduces the ability of the person in question to work in a safe manner and cope with emergency and evacuation procedure.

11) *Other disorders*
There must be no other disorders that result in non-conformity with the health and mobility requirements or that might lead to a need for acute medical treatment that cannot be provided offshore.

There must be no degree of obesity that would represent a safety risk in an emergency.

The health requirements in these regulations are not satisfied after the 28th week of pregnancy.

19.5 Potential contra-indications for work in cold climates

The IPIECA OGP-report no 398 describes potential contra-indications for work in extremes of temperature.

These contra-indications include:

- respiratory or cardiovascular problems;
- severe obesity (BMI $\geq$ 35); this impedes the acclimatization process;
- metabolic disorders (e.g. thyroid disease);
- alcohol abuse;
- pregnancy;
- previous heat- or cold-related illness.

Those potential contra-indications specific to cold include:
- Raynaud's syndrome (white finger);
- cold-induced asthma;
- cold-induced urticaria (an itchy skin condition);
- cryohaemoglobulinaemia (a rare blood condition).

Medications which may pose a problem in extremes of temperature include:
- medications that alter vigilance or sweating (tranquillizers, sleeping pills, antidepressants, antihistamines);
- medications that act on blood circulation (blood pressure and heart treatments);
- diuretics (medications that alter body fluid balance);
- drugs with antipyretic properties that may interfere with temperature regulation (for example many analgesics or antiinflammatories);
- photosensitizers (both systemic and topical), which increase the skin's reaction to sunlight.

19.6 Medical examination

ISO 12894:2001 (Annex D – Medical supervision of individuals exposed to cold environments in the laboratory) describes that "Where a medical examination is performed, a thorough clinical assessment should be made with particular attention to the factors which may predispose to illness due to cold". Furthermore, the standard suggests that inclusion of a system of medical supervision of the exposed individuals in risk management may entail both medical fitness assessment prior to exposure and health monitoring during exposure.

Medical fitness assessment should take place prior to exposure to extreme hot or cold environments. This should take account of the intended exposure conditions and is centered on the individual. It is intended to determine whether there are any reasons to consider that the person may be susceptible to ill effects from the planned environmental exposure (ISO 12894:2001, 4.2.2.2 Medical fitness assessment).

Assessment of the anticipated physiological strain, coupled with appropriate medical fitness assessment will, in most situations, provide adequate safeguards against the risk of illness occurring from exposure to hot or cold conditions. In the more extreme conditions the onset of ill health and the occurrence of symptoms may be rapid and some form of health monitoring is likely to be required to detect these changes and allow an early intervention. An example might be where the prediction of physiological strain is not practicable due to the type of clothing to be worn (ISO 12894:2001, 4.2.2.3 Health monitoring).

19.7 Checklists for identifying cold-related problems at work

Various checklists for identifying cold-related problems at work are described in standards and in the literature:

- ISO 12894:2001 - D.6 Medical fitness assessment questionnaire prior to cold exposure. In: Ergonomics of the thermal environment - Medical supervision of individuals exposed to extreme hot or cold environments
- ISO 15743:2008(E). Cold work health questionnaire. In: Ergonomics of the thermal environment - Cold workplaces - Risk assessment and management (APPENDIX B)
- Health-Check Questionnaire for Subjects Exposed to Cold (Hassi et al., 2003)
- The national FINRISK 2002 study (Raatikka et al., 2007)

These questionnaires include the prevalence of cold-related complaints, symptoms and diseases and identify individuals with cold-related diseases, complaints, or personal working limitations in the workplace.

As described in RN05 Working Environment (Barents Sea. Report no 2012-0690), ISO 15743 and ISO 12894 provide relevant guidance for conducting a health assessment of individuals for working in cold environments.

During a three-stage medical screening cold-related health assessment will be outlined:

- Stage 1: Health check using medically-based questionnaire (Annex D ISO 15743).(APPENDIX C)
- Stage 2: Interview and a clinical investigation of persons suspected of having a cold-related individual health problem.
- Stage 3: If there are still some open questions regarding the individual's health status or other cold consequences, a more detailed analysis in a hospital specialist unit or a provocation laboratory might be needed.

(RN05 Working Environment. Barents Sea. Report no 2012-0690).

Figure 19 shows an example of an occupational Health Care model for cold work developed by Hassi et al (2001a). The main content of occupational health care is based on the result of cold related risk assessment in the working environment and health check of working individuals.

Hassi et al. (2001a) explains the model as follows: "The purpose of health check is to find all potential individuals having cold related diseases or cold related personal working limitations. As a result of the first level it is recognised who are the individuals which need to be further analysed. The second level of the activities in medical screening is formed by further interviews and clinical status of the employees selected to this level. The content of the interviews and clinical investigations is dependent on the results of the preliminary health check and is symptom or disease specific. If cold related disease or working limitation is recognised, an additional health status based risk evaluation in the workplace may be needed. If there still remain open questions in the health status or other cold consequences, more detailed analysis in expert units in hospitals or provocation laboratories may be needed".

Further: "As a result of selection procedures occupational health-professionals accept or reject employees to work in cold environment. For employees working in the cold different types of advice, training and information is needed to achieve an optimal result in their health and working performance".

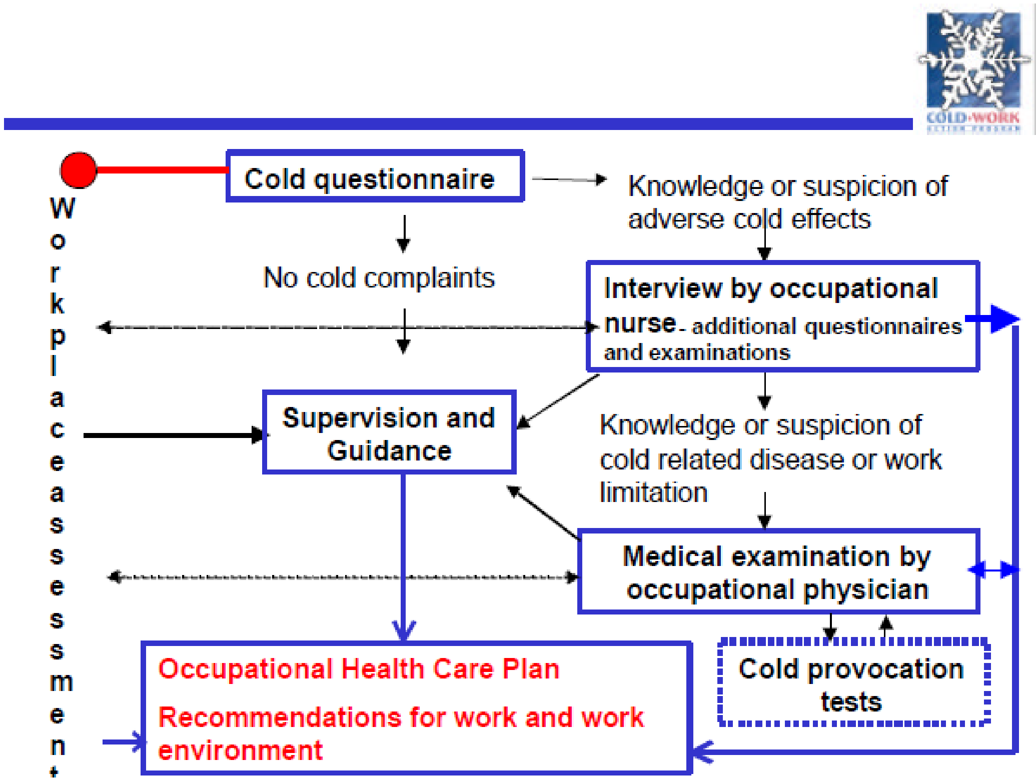

Figure 19 Occupational Health Care model for cold work (Hassi et al 2001).

19.8 Recommendations of health exclusion criteria for work in the cold

19.8.1 General recommendations

1. **The health requirements defined in "**The Norwegian FOR 2010-12-20 nr 1780: Forskrift om helsekrav for personer i arbeid på innretninger i petroleumsvirksomheten til havs, version 2.1 (01/2012) with more detailed descriptions in: Guidelines to Regulations regarding health requirements for persons working on installations in petroleum activities offshore (Norwegian Directorate of Health. IS-1879.2012) **should apply also for work in cold environments.**

2. **Health exclusion criteria for work in the cold must be identified at individual level, after a thorough medical examination of the employee concerned.**

3. **An occupational health care model for cold work should be implemented**. Cold-related health assessment processes should be performed as outlined in ISO 15743 and ISO 12894 as suggested in RN05.

4. **The medical fitness examination for cold work should include information about:**
   - Cold-related symptoms and diseases
   - anticipated physiological strain (work intensity, tasks)
   - anticipated cold exposure and duration

5. **Cold-related symptoms and diseases to be identified during the cold health check:**
   - respiratory symptoms
   - cardiovascular symptoms
   - metabolic disorders
   - musculoskeletal symptoms
   - cold sensitivity
   - cold urticaria
   - symptoms related to peripheral circulatory disturbances
   - symptoms related to white fingers
   - local cold injuries
   - the effect of cold on performance
   - use of medications

6. **Knowledge about risk factors**
   Both workers and medical personnel should know the signs and symptoms and risk factors for hypothermia, frostbite, and nonfreezing cold injuries, and have the latest up-to-date information about current and future weather conditions before performing a task. The wind-chill temperature index should be used to estimate the relative risk of frostbite.

Assessment of the anticipated physiological strain, coupled with appropriate medical fitness assessment will, in most situations, provide adequate safeguards against the risk of illness occurring from exposure to hot or cold conditions (ISO 12894).

19.8.2 Specific recommendations

The following recommendations can also be added to improve occupational safety and health for working in the cold:

Respiratory diseases

Since the mechanisms underlying cold air-provoked respiratory symptoms vary considerably and mainly depend on individual susceptibility and ventilation level during the cold exposure (asthmatic episodes are likely to occur in association with moderate and high exercise levels), a definitive conclusions regarding health exclusion criteria cannot be drawn.

However, in order to take into account the adverse effects of cold exposure on respiratory health, susceptible individuals who suffer from respiratory disease (e.g. asthma, COPD) should take some precautions (Makinen and Hassi, 2009):

- Work activity should be planned in such a way as to avoid or minimize very high physical activity levels.
- The intensity and duration of work in the cold should be regulated.
- Protection from facial cooling may diminish or prevent reflex bronchoconstriction and the related breathing difficulties (Koskela, 2007).
- Heat-exchanger masks should be used under conditions where cold-induced respiratory symptoms emerge.
- Medication should be adjusted to optimal levels, taking into account the effects of cold exposure on respiratory function.
- Individuals with asthma and cardiovascular disease can work in cold environments, but should be monitored closely.

Cardiovascular diseases

For managing the adverse cardiovascular effects of cold work, some possibilities to reduce or prevent these are suggested (Makinen and Hassi, 2009).

For *healthy persons* and at the beginning of the cold exposure, it is recommended:

- Physical exercise should be initiated gradually since both cold exposure and physical exercise increase blood pressure, and the effect can be at least to some extent additive.
- Sudden, intensive physical exercise should be avoided.

For cardiovascular patients

- Identify who is a “high responder” with regard to cold, and target the cold risk management methods accordingly.
- Employees with a coronary heart disease should receive advice on how to prevent cold-related adverse effects.

Raynaud`s phenomenon (RP) and Hand-arm vibration syndrome (HAV)

- Avoid cooling at work, if possible.
- It is particularly important for patients with RP and HAV to protect their extremities well.
- One of the key factors is appropriate organizational planning taking into account these special needs.
- Customised information and guidance should be given.

Metabolic disorders
For diabetics working in the cold:

- Advice is needed on the effects of cold, especially with reference to cardiovascular disease.
- Self-care and taking into account possible comorbidity during exposure to cold is important.

Musculoskeletal disorders
For reducing or preventing cold-related musculoskeletal problems it is suggested to have a special emphasis on cold risk management, and especially organizational measures would be useful (Makinen and Hassi, 2009). These might include:

- Planning of appropriate work-rest regimes
- Use of local and auxiliary heaters
- Reducing draughts
- Paying attention to proper cold protection. Individuals with a musculoskeletal disease need special advice on proper cold protection.

Frostbites
Prevention of frostbite includes:

- Appropriate advance planning, information and advice
- Organizational measures (adjustment of clothing, workspaces, work-rest regimes, coating or warming tools etc.).
- Special population groups (e.g. diabetics, patients with RP, persons with skin disorders or with previous frostbite) at work should in particular be given advice on proper protection
- Emollients are not recommended as they may increase the risk of frostbite (Lehmuskallio et al., 1995).

20 Slides and falls related to snow and ice

Objective: Suggest means of mitigating work-related injuries caused by of slides and falls due to snow and ice build-up and snowdrift on the installation.

20.1 Environmental, human and system factors

Cold injuries in feet are not the most common problems caused by unsuitable boots in cold environments. Injuries due to slipping and falling are more frequent (Gao and Abeysekera, 2004a) and the professional footwear provided does not provide enough protection against slips and falls (Gao et al., 2008).

Many factors contribute to the risk of slips and falls. Grönqvist and Hirvonen (1995) pointed out that the risk factors may include extrinsic (environmental), intrinsic (human) or mixed (system) factors. The *primary risk factor* is poor grip or low friction between footwear and the floor. *Secondary risk factors* for slipping accidents include a wide range of environmental and human factors, such as activity at time of fall; behavioural factors (e.g. moving at speed); task-related factors (e.g. carrying objects or visual distractions); individual intrinsic factors (e.g. visual, vestibular, proprioceptive and musculoskeletal functions, balance, illness) (Gao et al., 2008).

Tisserand (Tisserand, 1985) included the following factors as contributing to slips:
- Biomechanical and psychological factors involved in walking.
- Factors related to the floor surface.
- Characteristics of shoes and soles.

Gao and Abeysekera (2004a) put forward a systems model of slip and fall accident on icy surfaces. The model explains the following factors, which contribute to slip and fall accidents:
- Footwear (sole) properties including sole material, hardness, roughness, worn/unworn, tread (geometry) design, center of gravity, anti-slip devices, wearability (weight, height, flexibility, ease of walking, comfort), etc.
- Underfoot surface characteristics, covered by ice, snow, contaminants, anti-slip materials, uneven, ascending/descending slope, etc.
- Footwear (sole)/surface interface - tribological aspects, i.e., coefficient of friction (static, transitional and dynamic).
- Human gait biomechanics: muscle strength, postural control, musculoskeletal function, postural reflex and sway, balance capability, acceleration, deceleration, stride length, step length, heel contact velocity, transition of the whole body centre of mass, vertical and horizontal forces, required COF.
- Human physiological and psychological aspects, i.e., the so-called intrinsic factors, including decline in visual, vestibular and proprioceptive functions, ageing, perception of slipperiness, information processing, experience, training, diabetes, drug and alcohol use, unsafe behavior (rushing, reading while walking) etc.
- Environment (extrinsic factors): temperature, snowfall, lighting, etc.

Prevalence

It has been suggested that slips cause 16% of all accidents and 43% of all falls at work, in the home and during leisure activities in the Nordic countries (Gronqvist and Hirvonen, 1995). Two-thirds of these slips occur on pavements or other surfaces covered by ice or snow. Falls occur most frequently on ice covered with snow due to the difficulty of perceiving hidden risks in order to adjust gait strategies (Gao et al., 2008). In a study with postal delivery service showed that the majority (70%) of slips, trips and falls involved snow and ice (Haslam and Bentley, 1999).
The factors identified as contributing to injuries initiated by slips and trips in the largest construction projects in the world between 1989 and 1994 were mainly environmental (including trenches, dirt

clods, dust, snow, ice, mud and weather), of which the condition of the walking surface contributed to 50% of the injuries The vast majority of injuries were sprains, strains and contusions. Non-fall slips and trips caused a significant number of musculoskeletal injuries, which were reported as the most costly injuries (Lipscomb et al., 2006). Due to the decrease in friction under icy conditions, the proportion of fractures increases, with a redistribution of lesions on the lower extremities towards the proximal end of the limb (Merrild and Bak, 1983).

Slipping and Coefficient of friction (COF)
Slips occur when the coefficient of friction (COF) between footwear and walkway surface provides insufficient resistance to counteract the resultant force. Slipping is due to fairly complex causal pathways, involving both environmental and human factors (Courtney et al., 2001). The primary environmental factor behind slipping accidents is the slip resistance characteristics of the underfoot surface (Gronqvist et al., 2001). Particularly in winter, when surfaces are often covered by ice, snow, slush or frost, slipping accidents are mainly due to the inadequate grip between footwear and underfoot surfaces. In general, slipperiness is defined quantitatively as a coefficient of friction between surfaces, which is a measurable physical quantity. Measured coefficient of friction values are related to subjective evaluations using e.g. the grading system presented in Table 1.

Table 1. The grading system relating the dynamic coefficient of friction to the subjective evaluations (Gronqvist and Hirvonen, 1995).

Class	**Explanation**	**Coefficient of kinetic friction**
1	Very slip-resistant	>0.30
2	Slip-resistant	0.20–0.29
3	Unsure	0.15–0.19
4	Slippery	0.05–0.14
5	Very slippery	<0.05

Friction higher than 0.20 is usually regarded as safe when walking on level surfaces (Gronqvist and Hirvonen, 1995). In other situations, such as when walking on inclined surfaces, carrying a heavy load or running, a higher coefficient of friction may be needed to prevent slipping. The level of friction ought to be even higher than 0.40 for some special groups (Dura et al., 2005).

The interaction at the interface between the footwear sole and underfoot surface is one of the primary factors causing slips and falls (Gronqvist et al., 1999, Abeysekera and Gao, 2001), which in turn is dependent on the properties of ice and sole. Sole wear and ice temperature are two important determinants of the COF at the interface (Manning et al., 1985, Gronqvist and Hirvonen, 1995, Hirvonen et al., 1998).

Slip resistance may decrease or increase depending on soling materials, the duration of wear and type of wear (Manning et al., 1985, Gronqvist and Hirvonen, 1995, Hirvonen et al., 1998). The natural use of boots on oily surfaces for a period of more than one year was tested by Manning et al. (1985). The results showed that, in general, the friction fluctuated over the course of wearing. For polyurethane (PU) material, an improvement in friction was recorded after a short period of wear. This result is consistent with those obtained by Leclercq et al. (1994) and Gronqvist (1995).

Little research and no standards are available regarding the measurement of slipperiness between icy and snowy surfaces and footwear. At present, there is no standard for COF on icy and snowy surfaces (Gao and Abeysekera, 2004a).

SINTEF

Footwear properties

Several factors of the footwear affect footwear and slip resistance properties:

- Sole materials
- Sole tread (geometry) pattern
- Sole hardness
- Wear and tear
- Asperity (roughness)

Soling materials

A PU sole is the most slip resistant soling for use on oily and wet floors (Manning et al., 1985, Manning and Jones, 1994, Gao et al., 2003). Grönqvist and Hirvonen (1995) recommended soft heel and sole materials of thermoplastic rubber (rather than PU) for winter footwear for use on dry ice (-10°C), believing that PU was not safe enough on wet ice (0°C).
The coefficient of friction on melting and hard ice showed that on melting ice, all types of footwear soles had lowest COF. Crepe rubber is recommended for use on hard ice (Gao et al., 2003).
There seems to be no universal soling material which is slip-resistant on different icy surfaces, e.g., dry and wet ice. In terms of practical use, these results mean that it is challenging to design proper anti-slip footwear for use on all types of icy and snowy surfaces in winter, because it is unlikely that one soling material/tread design can accommodate various climatic conditions and changeable icy and snowy surfaces (Gao and Abeysekera, 2004a).

Sole tread (geometry) pattern

Besides sole materials, sole (geometry) pattern also affects slip resistance. Different surfaces may require different tread designs in order to achieve higher friction.

Sole hardness

Bruce et al. (1986) showed that there was a negative correlation between sole hardness and COF on ice (dry ice, -9°C, r= -0.876). The poor friction properties on ice of hard materials have been reported.

Wear and tear

The slip resistance of a shoe is not a stable property. It varies in the course of use. Grönqvist and Hirvonen (1995) recommended discarding footwear before the tread pattern is worn out.

The slip resistance properties of different types of footwear have been found to differ significantly (Aschan et al., 2009). The sole needs to be designed according to the intended use of the footwear to avoid slipping and stumbling (Kuklane et al., 2009).

Significant differences between the slip resistance characteristics of footwear indicates the importance of selecting the right footwear for the prevention of slipping accidents, particularly during normal climate winters, when friction provided by slip-resistant footwear may be many times better than poorer footwear. Materials that have good friction on a lubricated metal plate are not necessarily good for ice and snow, as the materials tend to become hard in the cold and thus lose their grip. The materials and the friction properties of ice and snow change with different temperatures. Tests have shown that on wet ice practically all shoe materials are very slippery (Gao et al., 2003, Gao and Abeysekera, 2004b).

According to a study by Grönqvist et al (1995), the main effects, which explain most of the differences in the frictional properties of footwear were: 1) hardness/hardening of the heel and sole material 2) heel/sole material type 3) Cleat design.

The coefficient of friction (COF) of sole material should be tested:
- Above +5°C: Measured on moist or lubricated materials
- Below -10°C: Measured on hard ice
- Between +5 and -10°C: Measured by both methods.

A study by Gao et al. (2008) concluded that thermal insulation and the slip resistant properties of footwear are ranked as top requirements by users. Their most preferred preventive measures are footwear with anti-slip properties and the application of anti-slip materials, such as sand or salt.

Gait modifications
Based on mechanical testing hard-soled shoes have been shown to provide less available friction than soft-soled shoes. Subject wearing hard-soled shoes demonstrated decreased total body center of mass acceleration prior to and immediately following initial contact, lower walking velocity, shortened stride length and reduced ankle dorsiflexion angle at initial contact. According to Tsai and Powers (2009), these gait modifications represent behavioural adaptations to wearing shoes that are perceived to be more slippery.

20.2 Recommendations for mitigation of work related injuries caused by slides and falls due to snow and ice on installations

We suggest that recommendations for the mitigation of work related injuries caused by slides and fall due to snow and ice on installations should be divided into four sections:

1. Design requirements
2. Winter maintains
3. Footwear
4. Education and training

Each part is based on recommendations given in existing standards (NORSOK S002 and RN05 Working Environments – Barents Sea) and additional requirements:

20.2.1 Design requirements (working environment design requirements)

Anti-slip systems (NORSOK S002, Clause 5.1.2.0-19 and 20)

- *Proposed standard* – Slippery floor surfaces shall be avoided in work areas and access ways. Non-slip systems shall be installed in exposed stairways and stepladders, including the uppermost step at deck/platform level.

Anti-icing and de-icing (RN-05 Working Environment – Barents 2020) (Veritas, 2010))

- *Proposed standard* – Work area surfaces and access ways subject to snow, ice or frost accretion shall be provided with anti-icing or de-icing arrangements.

- Anti-icing arrangements (generally by means of heating or cover) shall have sufficient capacity to keep the area or equipment free of ice, snow or frost down to the facility's minimum design operating temperature, accounting for heat loss by applying a scaling factor related to a specified design wind speed.

- De-icing arrangements shall be sufficient to remove ice, snow or frost accumulations within a reasonable period of time (4-6 hours), under the icing conditions specified in the working environment design basis.

20.2.2 Winter maintenance

Application of anti-slip materials (additional suggestions - SINTEF)

The most common anti-slip materials are:

- Strewing sand on ice raises the slip resistance to a safer level, particularly on wet ice.
- Salt
- Asphalt mixtures containing reclaimed tyre rubber particles (AMRP) (Taniguchi et al. 1997)
- Spreading boiler slag, coke cinders, sand and crushed stone (gravel), etc. on ice or snow

Spreading sand and gravel could greatly increase the friction on wet ice. Sand was found to be the best anti-slip material spread on icy and snowy surfaces (Abeysekera and Gao, 2001).

20.2.3 Footwear

Footwear with anti-slip properties (RN05 Working Environment – Barents Sea)

- *Proposed standard* – Personnel shall be provided with insulated gloves and **anti-slip footwear** suitable for protecting the wearer under the relevant environmental conditions (cold, wind and water) as well as the type of work to be performed.

- Anti-slip footwear shall be designed to provide stable footing on snow- and ice-covered surfaces. Anti-slip footwear shall be non-static and non-sparking so as not to present an explosion risk.

Prevention of falls due to slipping- Outsole (NS-EN ISO 20345:2004. Personal protective equipment. Safety footwear)

- Cleated area (6.4.1)
- Cleat height (6.4.3)

Slip resistance requirements (NS-EN ISO 20345:2004/A1:2007. Personal protective equipment. Safety footwear)

- Safety footwear shall comply with one of the following clauses: A.2 or A.3 or A.4.
- A.2. Slip resistance on ceramic tile floor with sodium lauryl sulphate (SLS)
- A.3. Slip resistance on steel floor with glycerol
- A.4. Slip resistance on ceramic floor tile with SLS and on steel floor with glycerol

Footwear with anti-slip properties

- Crepe rubber soling is highly recommended for use on hard ice. Melting ice is much more slippery, and abrasive soles do not improve slip resistance (Gao et al., 2003).

- On dry ice: Soft heel and sole materials of thermoplastic rubber with as large a cleated area as possible are recommended for winter footwear (Gronqvist and Hirvonen, 1995).

- On wet ice: Very hard soling materials with sharp cleats in combination with a softer base material. New developments are needed (Gronqvist and Hirvonen, 1995).

- Slip-resistant footwear or anti-slip devices should be especially worn in 'peak days for slipping accidents', which are characterized by the average daytime temperature being slightly below 0 °C, temperature crosses the 0 °C mark and/or there is rain in some form (Aschan et al., 2009).

Attachable anti-slip devices

- In very slippery icy conditions no footwear may provide enough grip for safe walking and anti-slip devices should therefore be used in situations where hard, smooth ice is covered by a layer of water or dry snow.

20.2.4 Education and training

Information and better knowledge of:

- The importance of adequate footwear selection
- Winter maintenance.

Section III

Key elements for work in cold climate

21 Key elements for work in cold climate

Objective
Define key elements as input to a procedure for how to work in cold climate

Table 13 Key elements for work in cold climate, minimum requirements and suggestions of assessment method/standard.

Health and fitness	Risk indicator	Requirement	Assessment/standard/guideline
Health exclusion criteria's	Respiratory- Cardiovascular – Peripheral circulatory- Musculoskeletal- Dermatological- related diseases. Freezing and non-freezing injuries.	Define health requirements /exclusion criteria for cold work for persons working on installations in petroleum activities offshore	The Norwegian FOR 2010-12-20 nr 1780. Norwegian Directorate of Health. IS-1879.2012. ISO 12894:2001, Annex B and D ISO 15743:2008, Annex D ISO 11079: 2007, Annex B.3. RN05 – Barents 2020 OGP report 398 Ref. also chapter 18.
Medical supervision Health assessment	Respiratory- Cardiovascular – Peripheral circulatory- Musculoskeletal- Dermatological- related diseases. Freezing and non-freezing injuries.	Implement checklists for identifying cold-related problems at work	ISO 12894:2001 – D.6: Medical fitness assessment questionnaire prior to cold exposure ISO 15743:2008(E): Cold work health questionnaire RN05 – Barents 2020 Ref. also chapter 18.
Individual factors	Age, gender, fitness adaption, ethnicity, experience.	Implement checklists for identifying cold-related problems at work Workers and managers understand that individual differences in responses to cold climate exist, - allow for individual adjustments in e.g. clothing/work/rest schedule etc.	Check list ISO 15743:2008, Annex D Training and supervision See also chapter 10.

Hypothermia	Core temperature below 35°	Prevent decline in core temperature by proper clothing and protection	Not likely to occur in an occupational setting with proper clothing and activity Education and supervision about emergency situations that may cause hypothermia See also chapter 10.4
Nutrition and water intake	Increased energy expenditure in the cold, dehydration	Balanced nutrient rich diet, adequate fluid intake, minimize intake of caffeinated drinks when working in extreme cold for prolonged time	Include in the check list based on ISO 15743 Training and supervision See also chapter 10.8
Sleep disorders	Work in Arctic (cold/darkness) may affect sleep quality and can have a significant impact on performance and safety	Workers understand the requirement to obtain sufficient quality sleep, when provided with the opportunity to obtain it.	Include in the check list based on ISO 15743 OGP 488 Performance indicators for fatigue risk (2012) Training and supervision See also chapter 10.10
Shift work in the cold	Indications of reduced awareness during cold work at night	Workers and foremen should give extra attention to critical work tasks during work in the cold at night	Include in the check list based on ISO 15743 Training and supervision See also chapter 10.9
Psychosocial factors	Combination of cold and other psychosocial factors in the Arctic can affect feelings and moods of the workers, which again can affect performance	Leaders should give extra attention to the combined effects of cold and other psychosocial factors by positively influencing their motivation, wellbeing and safety. Analysis of the psychological effects of additional stressors found in the Arctic offshore environment, including cold, prolonged periods of darkness (polar winter) and light (polar summer), remoteness, isolation	NORSOK S-002 Clause 4.3.5 Barents 2020 5.2.2 Training and supervision See also chapter 11.4

Cold risk assessment	Risk indicator	Requirement	Assessment/standard/guideline
Precondition Cold exposure criteria in the design stage.	Eliminate as much as possible human work outside. Selection of appropriate physical environment design parameters.	Appropriate design for cold climate should be made on the basis of Met-Ocean data for the last 5 years at the geographical location of the installation. WCI analysis should be made on the basis the extreme values for the three coldest months.	Arctic Zones based on environmental conditions in the Barents Sea AARI ISO 19906 General guidelines on Met-Ocean information ISO 11079 – WCI equation See also Chapter 12
Outdoor operation analysis (stage 1)	Heavy lifting, manual operations, contact cooling, equipment, clothing, frostbite, other cold related problems.	A risk check list according to ISO 15743 should be implemented as part of a JHA analysis to identify cold related problems in an early stage. The checklist should be used to identify if corrective actions is needed. The checklist should be used a few times during the winter and whenever the nature of the work of the environment changes considerably. If corrective actions is needed – move on to stage 2	Job hazard/risk of occupational injuries NORSOK S-002, Clause 4.4.3. ISO 15743 cold risk assessment 3 stage method. See also chapter 16 fig. 13
Wind Chill Exposure (stage 2)	Prevent frostbite Target skin temperature of -4.8°C is used for a 5% risk of frostbite.	The formulas and methods contained in ISO 11079 shall be used for calculating the WCT and classifying cold exposure risk. Simulations shall be made for the three coldest months of the year.	ISO 11079, Annex B NORSOK S-002, Clause 4.4.9. See also chapter 13 and 15.
Level of physical activity(stage 2)	Avoid heat loss Whole body cooling	Level of heat production of activity will significantly affect the required protection in cold climate. ISO 8996 tables should be used in the outdoor operation analysis to determine the level of metabolic rate.	ISO 8996 Table A.2 tables are available showing metabolic rates for a variety of activities See also chapter 15
Work/rest/warm up regimes (stage 2)	In exposed areas, clothing alone may not be sufficient for preventing local or whole body cooling	HSE and/or work leader shall develop and implement a work/warm up regime for outdoor work in cold climate. Work regimes should be developed depending on the task and type of work (normal/shorter periods/emergency). A permit for cold work should be required before commencing	ISO 11079 OGP 398 Barents 2020 7.1.5 See also chapter 15 table 8, 9 and 10 for recommended duration of exposure during light/moderate activity and

		work under extreme cold conditions.	indoor recovery times..
Local cooling Contact cooling	Manual performance Risk of local frost injuries	For work below the freezing point, metal handles and bars should be covered by thermal insulating material. Also, machines and tools should be designed so that they can be operated without having to remove mittens or gloves.	ISO 13732 Part 3 ISO 15743 local cooling See also chapter 14 and 15.

Selection of appropriate clothing and PPE	**Risk indicator**	**Requirement**	**Assessment/standard/guideline**
Clothing	Clothing is a prerequisite for work in cold environment. Insufficient clothing insulation may cause unwanted cooling. At high activity there is a risk for accumulation of sweat and increased discomfort. Special attention should be given on the compatibility of protective clothing and PPE (eye protection, helmet).	Selection of appropriate protective clothing and PPE for cold work should be done on the basis of the workplace risk assessment. Clothing shall be provided to match the comfort and protection of the worker whilst facilitating outdoor work tasks. Clothing system should consist of under, middle and outer layer and have the possibility to be adjusted for the level of required activity and environmental conditions (air temperature, precipitation). The clothing outer layer must allow for heat dissipation through evaporation and transport of sweat outwards in the clothing system Protective clothing for work in extreme cold should be designed to prevent drops in skin temperature below a mean of 28°C or below 15°C (extremities) at any time.	OGP 398 – General guidelines on clothing ISO 11079 - IREQ EN 342, EN 343 A multi-layered clothing system is ideal, with each layer serving a specific purpose: Inner layer (underwear): moisture absorption and transport. Middle layer (shirt, sweater): insulation and moisture transport. Outer layer (wind breaker, arctic clothing, rain gear): protection against the external environment and moisture transport. Cotton is not recommended. See also chapter 14.
Slips and falls Foot protection	Slides and falls Cold feet	Good grip on icy surfaces, since injuries frequently are caused by slipping and falling.	NORSOK S-002 clause 5.1.2.0-19 and 20: Anti-slip systems. Barents 2020: RN-05: Anti-icing and de-icing/Footwear with anti-slip

			properties. EN ISO 20345:2004: Prevention of falls due to slipping/slip resistance requirements. OGP 398 See also chapter 18.
Hand protection	Cold climate is associated with difficulties working with cold hands and fingers. Manual performance declines at hand skin temperatures below 24°C (low strain). Nerve conduction is reduced at finger temperature of 15°C .	Adequate hand protection shall be provided which can both keep the hands of the wearer warm and enable him to perform the fine motoric work with hand and fingers. Hand temperature should not fall below 15°C.	Mittens is recommended. Coverage also for underarm. Scooter-mittens and scooter-gloves with "thinsulate" material are best. ISO 11079 Annex B EN 511 - required insulation for hand-wear See also chapter 14.
Face and eye protection	Frostbite on bare skin Icing on eye protection Compatibility with helmet Airway cooling	In case of high wind chill conditions, a face mask (asthmatic filter mask) should be used. Wearing full covering face mask or head-over should not reduce the effect of the hearing protection or cause dew problems.	Full-face coverage when WCI is -24°C or lower. ISO 11079 – lowest temperature of inhaled air: At temperatures below – 15°, respiratory protection is recommended at high activity levels At temperatures below -30°C, respiratory protection is strongly recommended.

Training and supervision	Risk indicator	Requirement	Assessment/standard/guideline
Training and supervision for work in the Arctic	Personnel are able to recognize cold stress and fatigue in themselves and others. Personnel are able to use alertness strategies effectively to overcome the effects of fatigue associated with extended hours of work outdoors or continuous operations involving shift changes.	Training shall provide personnel with new knowledge and skills about working in the cold. Workers need to apply and practice the knowledge to become competent. Workers and supervisors involved with work in cold environments should be informed about symptoms of adverse effect exposure to cold, proper clothing habits, safe work practices, physical fitness requirements for work in cold, and emergency procedures in case of cold injury.	Competence is a combination of practical thinking skills, knowledge and experience. Training should include information about: • The hazards they are exposed to • Recognition of the symptoms of cold strain or injury in both themselves and others; • Any systems or control measures put in place by the employer • What they as individuals need to do to protect themselves from cold • Measurement of environmental conditions • The correct type of personal protection to be worn; • Physical fitness, health risk and other individual factors; • Emergency procedures that must be followed OGP 398..
Buddy system	Risk of local (frostbite, manual performance) and whole body cooling.	A buddy control system should be implemented at all work operations in the cold/ extreme climates.	OGP 398 Watch out for early warning signs of excessive cold stress in the other person. White spots/cold hands/discomfort Allow for breaks, essential not only for health but also for increasing productivity.

Cold risk management	Risk indicator	Requirement	Assessment/standard/guideline
Identification	Employers are to determine whether cold-related hazards are significant and should control significant hazards by means of elimination, isolation (where elimination is not possible or practicable), minimization, where isolation is not possible or practicable.	A cold risk management system should be implemented in the general risk management and occupational health and safety plans of the employer. The plan should include both cold risk assessment and health risk management system. The management plan should include e.g instructions for use, examples of concrete risks, cold and health risk checklist, information about protective clothing, training and supervision.	It is recommended to follow the stepwise model of ISO 14743 (see fig 13 in this document). ISO 15743 and ISO 12894 See also chapter 16..
Planning and organizing	Control the duration and intensity of cold exposure, provide sufficient time, measures and space for recovery	Use the IREQ model to decide on work/rest regimes and to adjust workloads to avoid excessive sweating. Use a buddy monitoring system to check for white spots/subjective reaction to cold.	ISO 11079 See also chapter 15. A list of technical cold risk management should be prepared. Including e.g selection of tools and machinery adapted for cold climate, reduction of slippery surfaces, sufficient lighting, reducing the risk of touching cold surfaces.
Technical preventive measures			
Surveillance and monitoring	Risk of local (frostbite, manual performance) and whole body cooling.	A system of continuous environmental monitoring should be implemented of all open and semi-open areas of the platform/installation where workers are expected to be exposed to WCT below -10 °C and the duration of outdoor activity is expected to exceed 40 minutes. These areas should be identified in the design stage of the planning and risk assessment of cold exposure.	Barents 2020 stage 4 OGP 398 See also chapter 17.
Heating and shelter	Risk of local (frostbite, manual performance) and whole body cooling.	For continuous work in temperatures below the freezing point heated warming shelter should be	OGP 398 See also chapter 15.4.

		available General or spot heating on the work site to increase temperature. Shielding of the work area from the wind. Provision of heated shelters on the work site.	
Tools and machinery	Risk of local (frostbite, manual performance) cooling.	A list of technical cold risk management should be prepared when performing the stage 1 cold risk assessment. This analysis should include selection of tools and machinery adapted for cold climate, as well as reduction of slippery surfaces, sufficient lighting, reducing the risk of touching cold surfaces.	ISO 15743.risk assessment ISO 13732 cold surfaces Metal tools and instruments can be coated which is an efficient method for reducing conductive cooling and frostbite risk. Insulation may also be added to the specific site of garment contact, e.g. to the palm side of the glove. Additionally, external heating sources can be used to warm the work or recreational environment. See also chapter 15.5 in this report.
Reduction of slippery areas	Risk of falling	The main access ways shall be protected from ice and snow. Stairs and ladders in regular use in open and semi open areas shall be protected or heat traced to avoid build-up of snow and ice	NORSOK S-002, 5.1.2.0-19 OGP 398 See also chapter 18.
Lighting	Risk of low visibility during bad weather conditions and polar winter (darkness)	Provision shall be made to ensure ambient lighting of the outdoor working areas – special attention should be given to lighting where tasks that are normally performed during daytime is to be performed at night with combination of darkness and cold	NORSOK S-002 Clause 4.4.8 Barents 2020 6.5
Insulation of work area	Protection against falling ice	Escape ways, access ways and work areas shall not be exposed to risk of falling ice from structures above	Barents 2020 – stage 4 / 6.1.2.

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Appendix

APPENDIX A – IREQ analysis

Table 1 IREQ-analysis of Clothing concept 1 at low work intensity

T_A	Wind speed	T_{WC}	$IREQ_{min}$	$IREQ_{neutral}$	Icl_{min}	$Icl_{neutral}$	DLE_{min}	$DLE_{neutral}$
0 °C	0.4 m/s	0 °C	1.9	2.2	2	2.3	3.9	1.6
-5 °C	0.4 m/s	-5 °C	2.3	2.6	2.4	2.7	1.5	1
-10 °C	0.4 m/s	-10 °C	2.7	3	2.8	3.1	0.9	0.7
-15 °C	0.4 m/s	-15 °C	3	3.4	3.2	3.6	0.7	0.5
-20 °C	0.4 m/s	-20 °C	3.4	3.8	3.6	4	0.5	0.4
-25 °C	0.4 m/s	-25 °C	3.8	4.2	4	4.4	0.4	0.4
-30 °C	0.4 m/s	-30 °C	4.2	4.6	4.4	4.8	0.4	0.3
-35 °C	0.4 m/s	-35 °C	4.6	5	4.8	5.2	0.3	0.3
-40 °C	0.4 m/s	-40 °C	5	5.4	5.3	5.6	0.3	0.3
0 °C	5 m/s	-4.9 °C	2.1	2.4	2.9	3.4	0.8	0.6
-5 °C	5 m/s	-11.2 °C	2.5	2.8	3.5	4	0.6	0.4
-10 °C	5 m/s	-17.4 °C	2.8	3.2	4.1	4.5	0.4	0.3
-15 °C	5 m/s	-23.7 °C	3.2	3.6	4.6	5.1	0.3	0.3
-20 °C	5 m/s	-30 °C	3.6	3.9	5.2	5.7	0.3	0.3
-25 °C	5 m/s	-36.2 °C	4	4.3	5.7	6.2	0.2	0.2
-30 °C	5 m/s	-42.5 °C	4.4	4.7	6.3	6.8	0.2	0.2
-35 °C	5 m/s	-48.7 °C	4.8	5.1	6.9	7.4	0.2	0.2
-40 °C	5 m/s	-55 °C	5.2	5.5	7.5	8	0.2	0.2
0 °C	10 m/s	-7.1 °C	2.2	2.5	3.8	4.4	0.5	0.4
-5 °C	10 m/s	-13.7 °C	2.6	2.9	4.5	5.1	0.3	0.3
-10 °C	10 m/s	-20.3 °C	2.9	3.3	5.2	5.9	0.3	0.2
-15 °C	10 m/s	-26.9 °C	3.3	3.6	5.9	6.6	0.2	0.2
-20 °C	10 m/s	-33.6 °C	3.7	4	6.7	7.3	0.2	0.2
-25 °C	10 m/s	-40.2 °C	4.1	4.4	7.4	8	0.2	0.2
-30 °C	10 m/s	-46.8 °C	4.5	4.8	8.1	8.7	0.2	0.1
-35 °C	10 m/s	-53.4 °C	4.8	5.2	8.8	9.5	0.1	0.1
-40 °C	10 m/s	-60.1 °C	5.2	5.6	9.5	10.2	0.1	0.1
0 °C	15 m/s	-8.4 °C	2.2	2.6	4.4	5.1	0.4	0.3
-5 °C	15 m/s	-15.3 °C	2.6	2.9	5.2	5.9	0.3	0.2
-10 °C	15 m/s	-22.1 °C	3	3.3	6	6.8	0.2	0.2
-15 °C	15 m/s	-29 °C	3.4	3.7	6.8	7.6	0.2	0.2
-20 °C	15 m/s	-35.8 °C	3.7	4.1	7.7	8.4	0.2	0.1
-25 °C	15 m/s	-42.7 °C	4.1	4.5	8.5	9.2	0.1	0.1
-30 °C	15 m/s	-49.6 °C	4.5	4.8	9.3	10	0.1	0.1
-35 °C	15 m/s	-56.4 °C	4.9	5.2	10.1	10.9	0.1	0.1
-40 °C	15 m/s	-63.3 °C	5.3	5.6	11	11.7	0.1	0.1

Table 2 IREQ-analysis of Clothing concept 1 at moderate work intensity

T_A	Wind speed	T_{WC}	$IREQ_{min}$	$IREQ_{neutral}$	Icl_{min}	$Icl_{neutral}$	DLE_{min}	$DLE_{neutral}$
0 °C	0.4 m/s	0 °C	0.9	1.2	0.9	1.2	8	8
-5 °C	0.4 m/s	-5 °C	1.1	1.4	1.2	1.5	8	8
-10 °C	0.4 m/s	-10 °C	1.3	1.6	1.4	1.8	8	8
-15 °C	0.4 m/s	-15 °C	1.6	1.9	1.7	2	8	1.8
-20 °C	0.4 m/s	-20 °C	1.8	2.1	2	2.3	2.3	1
-25 °C	0.4 m/s	-25 °C	2.1	2.4	2.2	2.6	1.1	0.7
-30 °C	0.4 m/s	-30 °C	2.3	2.6	2.5	2.8	0.8	0.5
-35 °C	0.4 m/s	-35 °C	2.5	2.8	2.8	3.1	0.6	0.4
-40 °C	0.4 m/s	-40 °C	2.8	3.1	3	3.4	0.5	0.4
0 °C	5 m/s	-4.9 °C	1.1	1.4	1.5	1.9	8	2.9
-5 °C	5 m/s	-11.2 °C	1.3	1.6	1.8	2.3	8	1.1
-10 °C	5 m/s	-17.4 °C	1.5	1.8	2.2	2.6	1.3	0.7
-15 °C	5 m/s	-23.7 °C	1.8	2.1	2.5	3	0.7	0.5
-20 °C	5 m/s	-30 °C	2	2.3	2.9	3.4	0.5	0.4
-25 °C	5 m/s	-36.2 °C	2.2	2.5	3.2	3.7	0.4	0.3
-30 °C	5 m/s	-42.5 °C	2.5	2.8	3.6	4.1	0.3	0.3
-35 °C	5 m/s	-48.7 °C	2.7	3	4	4.4	0.3	0.2
-40 °C	5 m/s	-55 °C	2.9	3.3	4.3	4.8	0.2	0.2
0 °C	10 m/s	-7.1 °C	1.2	1.5	2	2.5	2.4	0.7
-5 °C	10 m/s	-13.7 °C	1.4	1.7	2.4	3	0.9	0.5
-10 °C	10 m/s	-20.3 °C	1.6	1.9	2.8	3.4	0.5	0.4
-15 °C	10 m/s	-26.9 °C	1.9	2.2	3.3	3.9	0.4	0.3
-20 °C	10 m/s	-33.6 °C	2.1	2.4	3.7	4.3	0.3	0.2
-25 °C	10 m/s	-40.2 °C	2.3	2.6	4.2	4.7	0.2	0.2
-30 °C	10 m/s	-46.8 °C	2.6	2.9	4.6	5.2	0.2	0.2
-35 °C	10 m/s	-53.4 °C	2.8	3.1	5.1	5.6	0.2	0.2
-40 °C	10 m/s	-60.1 °C	3	3.3	5.5	6.1	0.2	0.1
0 °C	15 m/s	-8.4 °C	1.2	1.5	2.3	2.9	1	0.5
-5 °C	15 m/s	-15.3 °C	1.5	1.8	2.8	3.4	0.6	0.3
-10 °C	15 m/s	-22.1 °C	1.7	2	3.3	3.9	0.4	0.3
-15 °C	15 m/s	-29 °C	1.9	2.2	3.8	4.4	0.3	0.2
-20 °C	15 m/s	-35.8 °C	2.1	2.4	4.3	4.9	0.2	0.2
-25 °C	15 m/s	-42.7 °C	2.4	2.7	4.8	5.4	0.2	0.2
-30 °C	15 m/s	-49.6 °C	2.6	2.9	5.3	5.9	0.2	0.2
-35 °C	15 m/s	-56.4 °C	2.8	3.1	5.8	6.4	0.1	0.1
-40 °C	15 m/s	-63.3 °C	3.1	3.4	6.3	7	0.1	0.1

Table 3 IREQ-analysis of Clothing concept 2 at low work intensity

T_A	Wind speed	T_{WC}	$IREQ_{min}$	$IREQ_{neutral}$	Icl_{min}	$Icl_{neutral}$	DLE_{min}	$DLE_{neutral}$
0 °C	0.4 m/s	0 °C	1.9	2.2	2	2.3	8	8
-5 °C	0.4 m/s	-5 °C	2.3	2.6	2.4	2.7	8	2.3
-10 °C	0.4 m/s	-10 °C	2.7	3	2.8	3.1	2.1	1.3
-15 °C	0.4 m/s	-15 °C	3	3.4	3.2	3.6	1.2	0.9
-20 °C	0.4 m/s	-20 °C	3.4	3.8	3.6	4	0.9	0.7
-25 °C	0.4 m/s	-25 °C	3.8	4.2	4	4.4	0.7	0.6
-30 °C	0.4 m/s	-30 °C	4.2	4.6	4.4	4.8	0.6	0.5
-35 °C	0.4 m/s	-35 °C	4.6	5	4.8	5.2	0.5	0.4
-40 °C	0.4 m/s	-40 °C	5	5.4	5.3	5.6	0.4	0.4
0 °C	5 m/s	-4.9 °C	2.1	2.4	2.9	3.4	1.7	1
-5 °C	5 m/s	-11.2 °C	2.5	2.8	3.5	4	0.9	0.7
-10 °C	5 m/s	-17.4 °C	2.8	3.2	4.1	4.5	0.7	0.5
-15 °C	5 m/s	-23.7 °C	3.2	3.6	4.6	5.1	0.5	0.4
-20 °C	5 m/s	-30 °C	3.6	3.9	5.2	5.7	0.4	0.3
-25 °C	5 m/s	-36.2 °C	4	4.3	5.7	6.2	0.3	0.3
-30 °C	5 m/s	-42.5 °C	4.4	4.7	6.3	6.8	0.3	0.3
-35 °C	5 m/s	-48.7 °C	4.8	5.1	6.9	7.4	0.3	0.2
-40 °C	5 m/s	-55 °C	5.2	5.5	7.5	8	0.2	0.2
0 °C	10 m/s	-7.1 °C	2.2	2.5	3.8	4.4	0.7	0.5
-5 °C	10 m/s	-13.7 °C	2.6	2.9	4.5	5.1	0.5	0.4
-10 °C	10 m/s	-20.3 °C	2.9	3.3	5.2	5.9	0.4	0.3
-15 °C	10 m/s	-26.9 °C	3.3	3.6	5.9	6.6	0.3	0.3
-20 °C	10 m/s	-33.6 °C	3.7	4	6.7	7.3	0.3	0.2
-25 °C	10 m/s	-40.2 °C	4.1	4.4	7.4	8	0.2	0.2
-30 °C	10 m/s	-46.8 °C	4.5	4.8	8.1	8.7	0.2	0.2
-35 °C	10 m/s	-53.4 °C	4.8	5.2	8.8	9.5	0.2	0.2
-40 °C	10 m/s	-60.1 °C	5.2	5.6	9.5	10.2	0.2	0.2
0 °C	15 m/s	-8.4 °C	2.2	2.6	4.4	5.1	0.5	0.4
-5 °C	15 m/s	-15.3 °C	2.6	2.9	5.2	5.9	0.4	0.3
-10 °C	15 m/s	-22.1 °C	3	3.3	6	6.8	0.3	0.3
-15 °C	15 m/s	-29 °C	3.4	3.7	6.8	7.6	0.3	0.2
-20 °C	15 m/s	-35.8 °C	3.7	4.1	7.7	8.4	0.2	0.2
-25 °C	15 m/s	-42.7 °C	4.1	4.5	8.5	9.2	0.2	0.2
-30 °C	15 m/s	-49.6 °C	4.5	4.8	9.3	10	0.2	0.2
-35 °C	15 m/s	-56.4 °C	4.9	5.2	10.1	10.9	0.2	0.1
-40 °C	15 m/s	-63.3 °C	5.3	5.6	11	11.7	0.1	0.1

Table 4 IREQ-analysis of clothing concept 2 at moderate work intensity

T_A	Wind speed	T_{WC}	$IREQ_{min}$	$IREQ_{neutral}$	Icl_{min}	$Icl_{neutral}$	DLE_{min}	$DLE_{neutral}$
0 °C	0.4 m/s	0 °C	0.9	1.2	0.9	1.2	8	8
-5 °C	0.4 m/s	-5 °C	1.1	1.4	1.2	1.5	8	8
-10 °C	0.4 m/s	-10 °C	1.3	1.6	1.4	1.8	8	8
-15 °C	0.4 m/s	-15 °C	1.6	1.9	1.7	2	8	8
-20 °C	0.4 m/s	-20 °C	1.8	2.1	2	2.3	8	8
-25 °C	0.4 m/s	-25 °C	2.1	2.4	2.2	2.6	8	2
-30 °C	0.4 m/s	-30 °C	2.3	2.6	2.5	2.8	2.5	1.2
-35 °C	0.4 m/s	-35 °C	2.5	2.8	2.8	3.1	1.3	0.8
-40 °C	0.4 m/s	-40 °C	2.8	3.1	3	3.4	0.9	0.6
0 °C	5 m/s	-4.9 °C	1.1	1.4	1.5	1.9	8	8
-5 °C	5 m/s	-11.2 °C	1.3	1.6	1.8	2.3	8	8
-10 °C	5 m/s	-17.4 °C	1.5	1.8	2.2	2.6	8	1.7
-15 °C	5 m/s	-23.7 °C	1.8	2.1	2.5	3	2.2	0.9
-20 °C	5 m/s	-30 °C	2	2.3	2.9	3.4	1.1	0.6
-25 °C	5 m/s	-36.2 °C	2.2	2.5	3.2	3.7	0.7	0.5
-30 °C	5 m/s	-42.5 °C	2.5	2.8	3.6	4.1	0.5	0.4
-35 °C	5 m/s	-48.7 °C	2.7	3	4	4.4	0.4	0.3
-40 °C	5 m/s	-55 °C	2.9	3.3	4.3	4.8	0.4	0.3
0 °C	10 m/s	-7.1 °C	1.2	1.5	2	2.5	8	2.3
-5 °C	10 m/s	-13.7 °C	1.4	1.7	2.4	3	3.7	1
-10 °C	10 m/s	-20.3 °C	1.6	1.9	2.8	3.4	1.1	0.6
-15 °C	10 m/s	-26.9 °C	1.9	2.2	3.3	3.9	0.7	0.4
-20 °C	10 m/s	-33.6 °C	2.1	2.4	3.7	4.3	0.5	0.4
-25 °C	10 m/s	-40.2 °C	2.3	2.6	4.2	4.7	0.4	0.3
-30 °C	10 m/s	-46.8 °C	2.6	2.9	4.6	5.2	0.3	0.2
-35 °C	10 m/s	-53.4 °C	2.8	3.1	5.1	5.6	0.3	0.2
-40 °C	10 m/s	-60.1 °C	3	3.3	5.5	6.1	0.2	0.2
0 °C	15 m/s	-8.4 °C	1.2	1.5	2.3	2.9	8	1
-5 °C	15 m/s	-15.3 °C	1.5	1.8	2.8	3.4	1.3	0.6
-10 °C	15 m/s	-22.1 °C	1.7	2	3.3	3.9	0.7	0.4
-15 °C	15 m/s	-29 °C	1.9	2.2	3.8	4.4	0.5	0.3
-20 °C	15 m/s	-35.8 °C	2.1	2.4	4.3	4.9	0.4	0.3
-25 °C	15 m/s	-42.7 °C	2.4	2.7	4.8	5.4	0.3	0.2
-30 °C	15 m/s	-49.6 °C	2.6	2.9	5.3	5.9	0.2	0.2
-35 °C	15 m/s	-56.4 °C	2.8	3.1	5.8	6.4	0.2	0.2
-40 °C	15 m/s	-63.3 °C	3.1	3.4	6.3	7	0.2	0.2

Table 5 IREQ-analysis of clothing concept 3 at low work intensity

T_A	Wind speed	T_{WC}	$IREQ_{min}$	$IREQ_{neutral}$	Icl_{min}	$Icl_{neutral}$	DLE_{min}	$DLE_{neutral}$
0 °C	0.4 m/s	0 °C	1.9	2.2	2	2.3	8	8
-5 °C	0.4 m/s	-5 °C	2.3	2.6	2.4	2.7	8	8
-10 °C	0.4 m/s	-10 °C	2.7	3	2.8	3.1	8	2.4
-15 °C	0.4 m/s	-15 °C	3	3.4	3.2	3.6	2.2	1.4
-20 °C	0.4 m/s	-20 °C	3.4	3.8	3.6	4	1.3	1
-25 °C	0.4 m/s	-25 °C	3.8	4.2	4	4.4	1	0.8
-30 °C	0.4 m/s	-30 °C	4.2	4.6	4.4	4.8	0.7	0.6
-35 °C	0.4 m/s	-35 °C	4.6	5	4.8	5.2	0.6	0.5
-40 °C	0.4 m/s	-40 °C	5	5.4	5.3	5.6	0.5	0.5
0 °C	5 m/s	-4.9 °C	2.1	2.4	2.9	3.4	3.8	1.6
-5 °C	5 m/s	-11.2 °C	2.5	2.8	3.5	4	1.5	1
-10 °C	5 m/s	-17.4 °C	2.8	3.2	4.1	4.5	0.9	0.7
-15 °C	5 m/s	-23.7 °C	3.2	3.6	4.6	5.1	0.7	0.5
-20 °C	5 m/s	-30 °C	3.6	3.9	5.2	5.7	0.5	0.4
-25 °C	5 m/s	-36.2 °C	4	4.3	5.7	6.2	0.4	0.4
-30 °C	5 m/s	-42.5 °C	4.4	4.7	6.3	6.8	0.4	0.3
-35 °C	5 m/s	-48.7 °C	4.8	5.1	6.9	7.4	0.3	0.3
-40 °C	5 m/s	-55 °C	5.2	5.5	7.5	8	0.3	0.3
0 °C	10 m/s	-7.1 °C	2.2	2.5	3.8	4.4	1.1	0.7
-5 °C	10 m/s	-13.7 °C	2.6	2.9	4.5	5.1	0.7	0.5
-10 °C	10 m/s	-20.3 °C	2.9	3.3	5.2	5.9	0.5	0.4
-15 °C	10 m/s	-26.9 °C	3.3	3.6	5.9	6.6	0.4	0.3
-20 °C	10 m/s	-33.6 °C	3.7	4	6.7	7.3	0.3	0.3
-25 °C	10 m/s	-40.2 °C	4.1	4.4	7.4	8	0.3	0.3
-30 °C	10 m/s	-46.8 °C	4.5	4.8	8.1	8.7	0.2	0.2
-35 °C	10 m/s	-53.4 °C	4.8	5.2	8.8	9.5	0.2	0.2
-40 °C	10 m/s	-60.1 °C	5.2	5.6	9.5	10.2	0.2	0.2
0 °C	15 m/s	-8.4 °C	2.2	2.6	4.4	5.1	0.7	0.5
-5 °C	15 m/s	-15.3 °C	2.6	2.9	5.2	5.9	0.5	0.4
-10 °C	15 m/s	-22.1 °C	3	3.3	6	6.8	0.4	0.3
-15 °C	15 m/s	-29 °C	3.4	3.7	6.8	7.6	0.3	0.3
-20 °C	15 m/s	-35.8 °C	3.7	4.1	7.7	8.4	0.3	0.2
-25 °C	15 m/s	-42.7 °C	4.1	4.5	8.5	9.2	0.2	0.2
-30 °C	15 m/s	-49.6 °C	4.5	4.8	9.3	10	0.2	0.2
-35 °C	15 m/s	-56.4 °C	4.9	5.2	10.1	10.9	0.2	0.2
-40 °C	15 m/s	-63.3 °C	5.3	5.6	11	11.7	0.2	0.2

Table 6 IREQ-analysis of clothing concept 3 at moderate work intensity

T_A	Wind speed	T_{WC}	$IREQ_{min}$	$IREQ_{neutral}$	Icl_{min}	$Icl_{neutral}$	DLE_{min}	$DLE_{neutral}$
0 °C	0.4 m/s	0 °C	0.9	1.2	0.9	1.2	8	8
-5 °C	0.4 m/s	-5 °C	1.1	1.4	1.2	1.5	8	8
-10 °C	0.4 m/s	-10 °C	1.3	1.6	1.4	1.8	8	8
-15 °C	0.4 m/s	-15 °C	1.6	1.9	1.7	2	8	8
-20 °C	0.4 m/s	-20 °C	1.8	2.1	2	2.3	8	8
-25 °C	0.4 m/s	-25 °C	2.1	2.4	2.2	2.6	8	8
-30 °C	0.4 m/s	-30 °C	2.3	2.6	2.5	2.8	8	3
-35 °C	0.4 m/s	-35 °C	2.5	2.8	2.8	3.1	4	1.5
-40 °C	0.4 m/s	-40 °C	2.8	3.1	3	3.4	1.8	1
0 °C	5 m/s	-4.9 °C	1.1	1.4	1.5	1.9	8	8
-5 °C	5 m/s	-11.2 °C	1.3	1.6	1.8	2.3	8	8
-10 °C	5 m/s	-17.4 °C	1.5	1.8	2.2	2.6	8	8
-15 °C	5 m/s	-23.7 °C	1.8	2.1	2.5	3	8	1.9
-20 °C	5 m/s	-30 °C	2	2.3	2.9	3.4	2.5	1.1
-25 °C	5 m/s	-36.2 °C	2.2	2.5	3.2	3.7	1.2	0.7
-30 °C	5 m/s	-42.5 °C	2.5	2.8	3.6	4.1	0.8	0.6
-35 °C	5 m/s	-48.7 °C	2.7	3	4	4.4	0.6	0.4
-40 °C	5 m/s	-55 °C	2.9	3.3	4.3	4.8	0.5	0.4
0 °C	10 m/s	-7.1 °C	1.2	1.5	2	2.5	8	8
-5 °C	10 m/s	-13.7 °C	1.4	1.7	2.4	3	8	2
-10 °C	10 m/s	-20.3 °C	1.6	1.9	2.8	3.4	2.9	1
-15 °C	10 m/s	-26.9 °C	1.9	2.2	3.3	3.9	1.1	0.6
-20 °C	10 m/s	-33.6 °C	2.1	2.4	3.7	4.3	0.7	0.5
-25 °C	10 m/s	-40.2 °C	2.3	2.6	4.2	4.7	0.5	0.4
-30 °C	10 m/s	-46.8 °C	2.6	2.9	4.6	5.2	0.4	0.3
-35 °C	10 m/s	-53.4 °C	2.8	3.1	5.1	5.6	0.3	0.3
-40 °C	10 m/s	-60.1 °C	3	3.3	5.5	6.1	0.2	0.2
0 °C	15 m/s	-8.4 °C	1.2	1.5	2.3	2.9	8	2.3
-5 °C	15 m/s	-15.3 °C	1.5	1.8	2.8	3.4	3.6	0.9
-10 °C	15 m/s	-22.1 °C	1.7	2	3.3	3.9	1.1	0.6
-15 °C	15 m/s	-29 °C	1.9	2.2	3.8	4.4	0.7	0.4
-20 °C	15 m/s	-35.8 °C	2.1	2.4	4.3	4.9	0.5	0.3
-25 °C	15 m/s	-42.7 °C	2.4	2.7	4.8	5.4	0.4	0.3
-30 °C	15 m/s	-49.6 °C	2.6	2.9	5.3	5.9	0.3	0.2
-35 °C	15 m/s	-56.4 °C	2.8	3.1	5.8	6.4	0.3	0.2
-40 °C	15 m/s	-63.3 °C	3.1	3.4	6.3	7	0.2	0.2

Appendix B Medical fitness questionnaire

ISO 12894:2001(E)

D.6 Medical fitness assessment questionnaire prior to cold exposure

IN CONFIDENCE

This questionnaire should be completed prior to exposure to cold conditions. It is recommended that it is administered by someone with appropriate knowledge, for example, a nurse or trained laboratory scientist.

Please circle the appropriate response.

Name .... Date........./....../.......

Age .... years Sex: Male/Female

Present occupation ....

1.	Have you ever experienced episodes of fits or faints, or loss of consciousness (apart from concussion)?	Yes/No
2.	Do you suffer from thyroid or other general medical disease, for example, diabetes mellitus?	Yes/No
3.	Do you suffer from any disease of the heart or blood vessels, including high blood pressure?	Yes/No
4.	Do you suffer from Raynaud's phenomenon, or other peripheral vascular disease?	Yes/No
5.	Do you suffer from any chest disease, e.g. asthma or chronic bronchitis?	Yes/No
6.	Have you been treated for any serious mental ill health, or do you suffer from anxiety or depression?	Yes/No
7.	Do you suffer from any disease of the skin? If yes, please specify	Yes/No
8.	Do you suffer from any rheumatism or diseases of the joints?	Yes/No
9.	Do you currently take any medication? If yes, please specify	Yes/No
10.	Have you ever experienced any general or local allergic reaction to cold? If yes, please specify	Yes/No
11.	Have you ever suffered from any freezing or non-freezing cold injury? If yes, please specify	Yes/No

ISO 12894:2001(E)

12. Have you ever suffered an episode of low body temperature requiring medical treatment? Yes/No

If yes, please specify ....

....

....

13. If female, is it possible that you are now pregnant? Yes/No

NOTE If the reply to any question from 2-13 is yes, refer to the medical officer for advice. Note that prescribed or self-administered medication may impair physiological responses to the cold.

14. Do you smoke cigarettes or other tobacco? Yes/No

If yes, please specify ....

15. How often do you drink alcohol?

never/occasional/regular/daily

16. How often do you undertake exercise which leaves you out of breath?

never/occasional/regular/daily

17. Please give any other relevant comments here.

....

....

....

....

BRIEF EXAMINATION DETAILS

1. Height .... cm

2. Weight .... kg

3. Assessment of height and weight:

   e.g. Body Mass Index (weight in kg/height in m^2) ....

   % greater or less than recommended weight for height ....

4. Resting heart rate .... bpm

   sitting/lying (record posture)

5. Resting blood pressure ..../......... mmHg

   sitting/lying (record posture)

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Appendix C Cold Work Health questionnaire

ISO 15743:2008(E)

Annex D
(informative)

Cold work health questionnaire

D.1 Introduction

Cold causes many different health and performance risks in several lines of industries involving work outdoors or in cold indoor conditions (see ISO 12894 and ISO 9886). Cold work is taken here to mean *work in conditions where the ambient temperature is less than 10 °C or that causes a sensation of cold.*

The following questionnaire can be used to form guidelines for further examinations based on a health check. In the questionnaire, the worker is able to describe how he or she considers the effects of cold on his/her own personal health and performance. Based on the responses, the occupational health care unit, in co-operation with the worker him/herself, can then evaluate the possible need for supportive actions. The questionnaire is confidential and answering it is optional.

D.2 Occupational health care guidelines (for further examinations based on a health check)

Key

(white box)	No need for further investigation
(grey box)	Requires further investigation/specific interview

Cold sensitivity

1. How do you generally feel in the cold?

	Very unpleasant	Unpleasant	Slightly unpleasant	Pleasant
a) Whole body	1	2	3	4
b) Fingers	1	2	3	4
c) Toes	1	2	3	4

Detailed interview of performance **if** the respondent has answered in Question 12 that — considering concentration or motivation — performance is decreased due to cooling.

2. Are you exceptionally sensitive to cold?

a) 1 No

b) 2 Yes

Detailed interview of cold sensitivity.

Cold urticaria

3. Do you experience an intense itching of the skin in the cold or after cold exposure, related to a superficial inflammation (eczema) or like a rash (urticaria)?

a) 1 No

b) 2 Yes

Detailed interview of cold urticaria.

Respiratory symptoms

4. Do you experience…

	In warm	In cold	In cold during exertion	Not at all
a) Shortness of breath?	1	2	3	4
b) Extended coughing or coughing fits?	1	2	3	4
c) Wheezing?	1	2	3	4
d) Increased excretion of mucus from the lungs?	1	2	3	4
e) Very profound rhinitis?	1	2	3	4

Detailed interview of respiratory function.

Cardiovascular symptoms

5. Do you experience…

	In warm	In cold	In cold during exertion	Not at all
a) Chest pain?	1	2	3	4
b) Cardiac arrhythmias?	1	2	3	4
c) High blood pressure?	1	2	3	4

Detailed interview of cardiovascular function.

Symptoms related to peripheral circulatory disturbances

6. Do you experience episodic…

	In warm	In cold	Not at all
a) Circulatory disturbances in hands and/or feet	1	2	3
b) Blurring of vision	1	2	3
c) Headache named migraine	1	2	3

Detailed interview of peripheral circulatory disturbances.

ISO 15743:2008(E)

Symptoms related to white fingers

7. Are your fingers exceptionally sensitive to cold?

a) 1 No

b) 2 Yes

Detailed interview of Raynaud phenomenon.

8. Is the colour of your fingers episodically changing to…

		In warm	In cold	Not at all
a)	White	1	2	3
b)	Blue	1	2	3
c)	Red/violet	1	2	3

Detailed interview of Raynaud phenomenon.

Symptoms related to musculoskeletal system

9. Do you experience…

		In warm	In cold	Not at all
a)	Neck/shoulder or upper extremity pain	1	2	3
b)	Back or hip pain	1	2	3
c)	Pain in lower extremities	1	2	3

Detailed interview of musculoskeletal symptoms.

10. If you have another symptom (e.g. dizziness, exceptional fatigue, dysmenorrhea, transient paralysis of limbs, transient memory loss), **under what conditions do you experience it?**

		In warm	In cold
a)	What symptom?	1	2
b)	What symptom?	1	2

Detailed interview of cold-related symptoms.

Local cold injuries

11. Have you ever had frostbite of blister grade or more severe?

a) 1 No
b) 2 Once
c) 3 Several times

Detailed interview of frostbite.

Effect of cold on performance

12. How does cold affect the following factors of your performance during work?

		Performance decreased due to symptoms	Performance decreased due to cooling	Improves performance	No effect
a)	Concentration	1	2	3	4
b)	Motivation	1	2	3	4
c)	Hand grip force	1	2	3	4
d)	Musculoskeletal endurance	1	2	3	
e)	Other — which?	1	2	3	
f)	Other — which?	1	2	3	

Detailed interview of performance.

APPENDIX D Concept WE impact assessment

4.4. MODIFIED Concept WE impact assessment (WEIA)

4.4.2.0-1 A concept WEIA analysis shall be performed during the concept selection phase to identify installation areas and vendor packages that need particular attention during design development and to provide input to concept selection and validation of the selected concept. The analysis shall be updated during concept definition and optimization/FEED, to summarize WE aspects of the selected concept as input to detailed engineering.

4.4.2.0-4 - exposure to cold stress/wind chill in open and semi-open areas.

When cold risk assessment according to the checklist in ISO 15743 Annex A A.2 identifies that corrective actions is considered necessary, stage 2 analysis shall include calculations of WCI, see 4.4.9,

4.4.9 Outdoor operations/cold stress

4.4.9.0-1 Outdoor operations analyses shall be carried out for open work areas and semi-open work areas, in order to identify and remedy potential problem areas due to overall exposure to temperature, wind, icing and precipitation, including investigation of the weather protection necessary to comply with WCI and other functional requirements identified in the analysis. The methods described in ISO 15743 stage 2 analysis should be followed.

4.4.9.0-2 The analysis shall be performed early in design/layout development, and shall be updated whenever the nature of the work or the work environment changes substantially, new preventive measures is introduced, design changes are made that will affect personnel's exposure to cold stress. The activity shall ensure that:

4.4.9.0-3 - workplaces in open and semi-open areas where there is frequent work with duration of 10 min or more are identified,

4.4.9.0-4 - the analysis includes WCI calculations for the identified workplaces, in combination with explosion load calculations. When calculating the WCI, verified meteorological data (combined wind and temperature) for yearly mean of the past five years should be used. In addition, WCI calculations based on the extreme values of the three coldest months. The equation in ISO/TR 11079, Annex D, should be used to calculate WCT.

4.4.9.0-5 – the risk associated with the WCT should be assessed by the table 5 in this report.

4.4.9.0-6 - the acceptability of the exposure to high WCIs is determined on the basis of the tables in chapter 15 in this report, taking into account the type of work, activity level and duration of stay in exposed areas, and assuming normal winter work clothing,

4.4.9.0-7 - where considered necessary, measures to avoid exposed workplaces or reduce the exposure to wind and/or precipitation are evaluated, e.g. redesign/relocation of equipment, windbreaks. Design/layout measures that are feasible with respect to both technical safety and working environment shall be identified for implementation in the design.

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