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# Safety at Work in Cold Environments and Prevention of Cold Stress

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**Abstract: The questions related to safety at work in cold environments and prevention of cold stress in working life are described in this article. Working in the cold environment is more dangerous than the same type of work in a warmer climate. All researchers have concluded that the frequency of accidents/versus temperature curves follow the U-shape with the minimum near 20˚C. The effects of low temperature can be divided into direct, typically frostbites, and indirect, of which the indirect effects, typically slipping accidents, are more common. In improving risk management in cold conditions the risk evaluation based on existing standards is the starting point. Prevention of risks in cold environments can be done by planning of work, technical measures like heating or reduction of cooling by protective clothing, training and other measures. Local heaters, shelters against bad weather, reduction of draught are good examples of means of improving working conditions and reducing accident risks. The local IR-heaters can increase skin temperature of fingers about 7˚C in normal cold work. The improvement of 3˚C can be reached by using insulating material in the handle of tools. By using these technical improvements we can reduce the health risks but also improve work performance and even energy savings at work places.**

**Key words:** Working in cold, Risk management, Accidents, Technical measures

## Introduction

It is very obvious that working in the cold environment is more dangerous than the same type of work in a warmer climate. Physical, manual and cognitive performance and body cooling are closely related to each other. Not only physiological functions and reaction times of individuals are slower when they are in cold, but also heavy clothing interferes with movements, perception and sensations[1, 2]. Often also problems of psychological adjustment occur because of the cold and darkness that is common to winter operations in cold regions. It has been shown that persons exposed to such conditions tend to show general unfavourable trends such as increased depression, dissatisfaction, insomnia and lack of motivation[3]. Since mechanical systems are not functioning well in cold, it is more risky to work with them. Very often also darkness, wind and slippery ground increase the hazards of cold working environments. Because of that, special safety precautions, prevention means and risk management are needed to avoid accidents and disasters in cold work places. In addition the productivity could be increased by improving cold working environment[3].

In Finland there are more than 500,000 people who have experienced cold to affect harmfully in their work environment[4, 5]. About 300,000 people, working in cold conditions indoors, have perceived cold as especially or rather inconvenient. In spite of the large number of people suffering from cold exposure, the effect of cold has not received enough attention and there are no specific recommendations or orders regulating the cold exposure and the health hazards of cold[6]. Emphasis on the pre-

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vention of illness and the maintenance of work capacity has increased the research on the effects of cold and wind on protective winter clothing, and other equipment.

In this article we describe the questions related to safety at work in cold environments and means of prevention against cold in working life. Material has been collected from different studies mostly carried out in Finland. At first the effects of cold on occupational safety are discussed. Then risk management process based on risk evaluation is described and at the end some practical case studies about prevention of cold are referred to.

## The Effect of Temperature on Occupational Accidents

We must have scientific evidence that there are cold related accident risks to prove that special cold relating risk management and control functions are needed at workplaces. Researchers have for a long time been interested in the effects of temperature on performance, occupational accidents and safe behaviour. Both laboratory and field studies can be found on this subject[7].

The temperature was found to have an effect on the frequency and incidence of accidents at the beginning of 19th century[8]. The conclusions were made from field studies carried out at projectile factories. The incidence rate had a minimum when the temperature was about 20˚C and it increased in warmer or colder temperatures (Fig. 1).

In the 1950's, in an experiment researchers measuring visual-motor performance on five successive days, divided their 20 subjects into four equal groups. One group was in a temperature of 12.5˚C, another 21.1˚C, the third 29.4˚C and the last in 42.2˚C. The researchers found that the best performance was at 21.1˚C[9].

In outdoor conditions the incidence of industrial accidents rose sharply in summer time, when the temperature was above 20˚C and in the winter when the temperature was low according to a German study[10]. The reasons mentioned for the accidents in the low temperatures were the slipperiness of the roads and working platforms, hands numb with cold and cold apathy. A U-shaped curve with the minimum in 17–23˚C was also presented when the effect of temperature on the safety behaviour was studied[11].

A clear seasonal rhythm was found in the incidence rate of accidents in the outdoor work[7]. The autumn was the most dangerous season. The circumstances were especially gloomy in autumn before frosts and snow. Thus, the incidence rate had a greater relationship with the amount of natural light than with the temperature or the depth of snow. The incidence rate was lowest in the winter. One reason for this may be the decrease of working

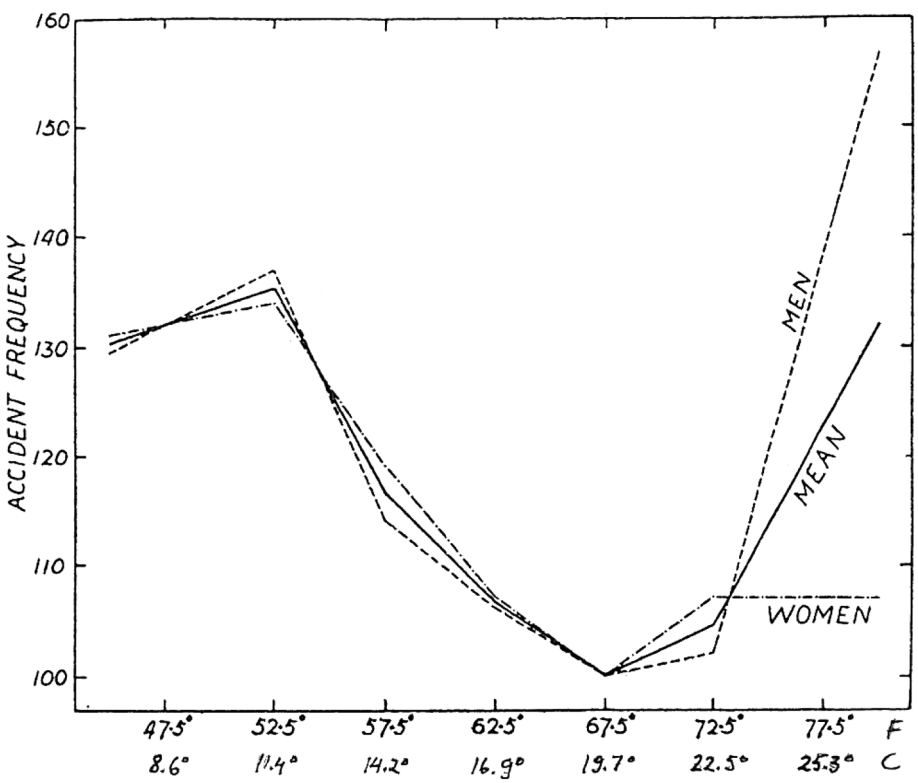


**Fig. 1. The temperature was found to have an effect on the frequency of accidents already at the beginning of 19th century.**

days during the coldest months. The construction work outside was stopped when the temperature was under –25˚C, according to the agreements.

In the mining industry in the USA a clear association was found between ambient temperature and occupational injuries[3]. As temperatures decreased, injury rates increased for both cold exposure injuries and slip and fall injuries, especially when the temperature was below 29˚F (–1.6˚C).

## The Direct and Indirect Effects of Cold

The effects of low temperatures on an individual man can be divided into direct and indirect effects, of which the indirect effects are more common[12]. An example of the direct effects of cold is frostbite. For instance 22% of reindeer herders reported having had a frostbite during one year when driving a snowmobile or doing other herding tasks according to a questionnaire[13].

The indirect effects of low temperatures are typically present in slipping and tripping accidents where the passages and working surfaces are of most importance. In some studies[14–16] snow and ice are mentioned to be the most important reasons to loose one's balance. The slipperiness of snow and ice considerably increases slipping and tripping in the wintertime.

Many indirect reasons for the increase of incidence rate of accidents when working in low temperatures have been found in many physiological and psychological studies[5, 17–20]. The cooling of tissues diminishes the tactile sensation of the skin and the dexterity of the fingers. Hands become weak, senseless and clumsy in the cold environment and mistakes increase. Thick clothing makes moving and functioning of the hands difficult. Intellectual functioning, making decisions, the reaction speed and the control of mental power become slower. The discomfort caused by low temperature may restrict the mental power so much that attentiveness and the ability to concentrate may decrease.

## Risk Evaluation as the Starting Point for Risk Management

The risk evaluation is the first step in risk management process when working in the cold environment. Local and general cooling can be evaluated according to ISO 11079[21]. In special cases also the risk of touching cold materials can be evaluated according to ISO 13732[22].

The combined cooling effect of cold and wind can be roughly estimated by the wind-chill-index, which describes the cooling of bare skin[23]. The insulation of clothing in cold work can be estimated by the IREQ-index[24]. When we know the metabolic power, effective mechanical power, ambient air temperature, mean radiant temperature of the environment, relative humidity, and air velocity, we can calculate the required insulation for the clothing.

The management and control of cold related health, performance and safety risks should be integrated comprehensively in the company's policies as well as in the company's occupational health and safety management systems[25]. Further, the evaluation of cold related adverse effects is an important aspect to be taken into account when estimating costs and benefits. By using standard, OHSAS 18001[26], it is easy to find guidelines for management of cold related risks and preventive measures based on the principal of continual improvement. The parts shown in the cold risk management model (Fig. 2) should be handled at workplaces[25].

## Prevention of Accident Risks in Cold Environments

In the prevention of accident risks in cold environments we have to pay attention to many items, like work area, slippery surfaces, working at heights as well as tools, equipment and machinery. There is a list of possible measures in Table 1[25].

In the following text we will review a few studies relating to prevention techniques.

*Infrared heaters in cold work places*

The local radiators are an effective protective measure in cold environments[27]. They suit well to warm fixed workplaces in large halls. In Fig. 3 there is an example about warming a fixed workplace by two local radiators. E.g. storages, repair halls as well as packing and loading halls of sawmills are suitable places.

The effect of the use of local heaters was seen in the temperature and heat loss of critical areas like shoulders and hands. The operative temperatures at different heights are presented with and without the heaters in Table 2. The heaters increased the temperature of the fingers even 7˚C, which is outstanding in computer work where finger dexterity is needed. The operative temperature near the head and the body increased to the optimal level. Good footwear is needed since the temperature at the level of the feet was much lower than near the body. The thermal sensations increased all over the body from cool to neutral. This occurred even if the worker was under the heaters only 50% of the working time.

The most important principles in the planning process of local heaters were:

- low temperature radiators are recommended
- the heating power is reversely proportional to the square of distance

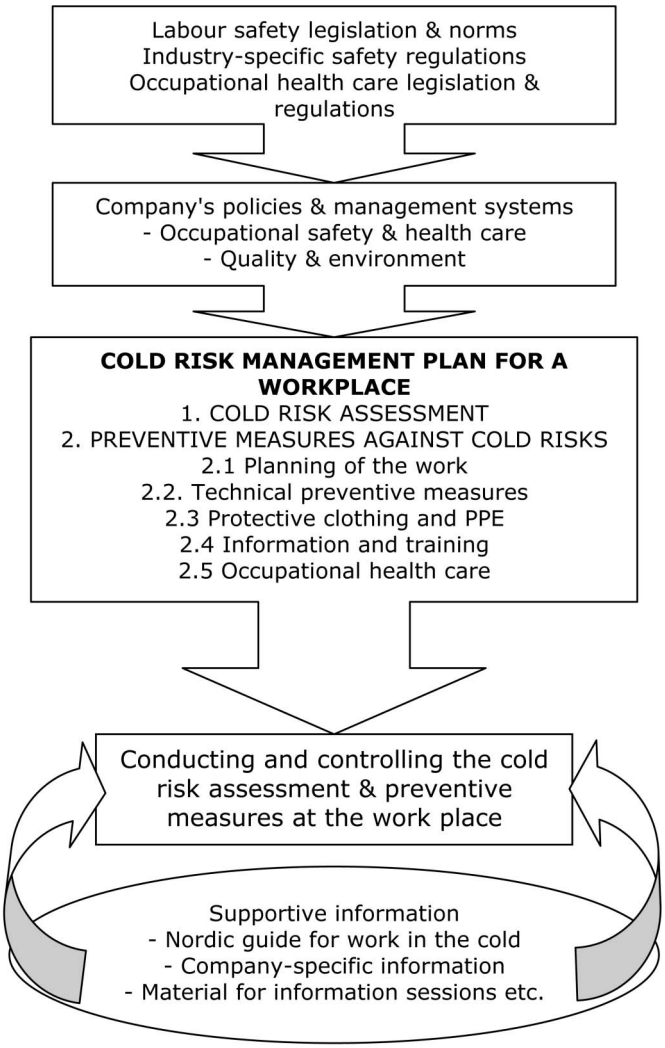


**Fig. 2. Cold risk management model for workplaces.**

- heating should be done at least from two directions
- heating should be directed downwards to one side of the body
- heating of head alone should be avoided.

*Tent as shelter against cold weather in machine repair*

A maintenance tent for terrain vehicles like snowmobiles and four-wheelers was developed for use in arctic wilderness[28, 29]. Attention was paid to occupational health and safety, and quality and efficiency of work. The objectives were that the tent and its energy should be transportable in a sledge and that the tent should bear the snow and wind load.

Possible heaters were sought to find the sufficient heating capacity down to a –35˚C outside temperature. The test showed that 0.75 kW/m$^2$ power was enough to hold the temperature inside at the desired level. The ventilation of the tent was carried out with the heater, which blew fresh air in and the tent was over-pressurized. The fan was also used as a local heater by conducting warm air to the hands and tools.

The functioning of the hands and fingers is of most importance to the safety in repair and service work, which is mainly done with different hand tools. The contact skin temperature of fingers was measured outside and in the tent (Fig. 4). The screw driver with plastic handle and the metallic ring wrench were compared to each other. When the repair work was carried out outside, the finger temperature was near the risk of cold injury. The temperature of fingers was near the comfort level, when repair work was carried out in the tent. The handles of tools should be made of heat insulating materials, which raised the contact skin temperature about 3˚C.

*Reduction of draught at workplaces*

The penetration of cold air into industrial buildings

**Table 1. A list of possible measures when preventing accidents in cold environments**

| | |
|---|---|
| Work area | - protect from heat loss to cold surfaces<br>- minimize air velocity in work zones<br>- keep workplace and passages clear from water, ice and snow<br>- insulate ground for stationary, standing work places<br>- ensure that the ground is solid before lifting heavy objects |
| Slippery surfaces | - avoid slippery materials and materials with different friction qualities in the same space<br>- ascertain that the inclination of floor or ground is adequate for water to flow to drain pit<br>- prevent building up of snow at entries with open shelters<br>- remove ice and snow from entries, passages, working floors and planes, machinery<br>- sand and maintain the passages regularly<br>- use warning signs, if the surfaces are slippery<br>- choose shoes with anti-slippery sole<br>- provide the shoes with anti-skid devices when working outdoors |
| Working at heights | - select stairs and ladders intended and tested for cold conditions<br>- ascertain that the ladders are firm and inspected according to regulations<br>- check the contact to the ground and anti-skid devices of the ladders<br>- remember safe declination of the ladders before climbing<br>- remove ice and snow from working planes<br>- check that falling is hindered by firm safety fences<br>- check that all the holes are covered up<br>- prevent motion on areas where falling is not hindered<br>- use safety belt or harness during work at heights |
| Tools, equipment, machinery | - select tools, machinery and equipment intended and tested for cold conditions<br>- select machinery intended for operation in cold environments<br>- store machinery in protected space and prewarm machinery and tools before use<br>- insulate handles and controls<br>- design handles and controls for operation by gloved hands<br>- conduct the repair and maintenance work indoors<br>- prepare for easy repair and maintenance under adverse conditions |

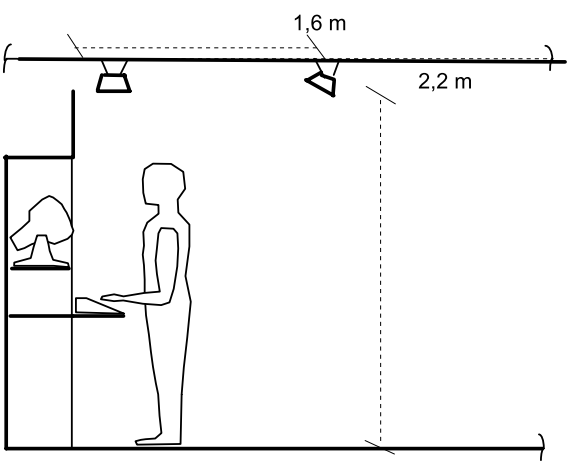


**Fig. 3. Two local heaters at computer work in a cold hall.**

through large open doorways increases the maintenance costs of the building and often causes a sensation of draught in the working areas[30]. Complaints of draught in workplaces have increased in Finland from 1977 through 1984, and were still increasing in 1993[31]. The opening of doors has been blamed for the variations in temperature and air flow in storerooms, packing houses, shipping departments, machine shops, metal workshops, and garages. In this kind of work over 40% of the employees work in colder than normal work environments, and half of the workers experience temperature fluctuations harmful for their work and well-being. The draught is most severe in foundries, where almost 70% of the workers considered draught to impair work[31].

One possibility of preventing cold air flows through the doorways is to install an air curtain on the opening[32]. When upwards blowing air is used, it is important that the air flow from the nozzle is evenly distributed along the full width of the doorway[33] and that the momentum of the blowing jet is sufficient[34]. The required momentum of the blowing jet depends on the pressure difference in the doorway.

The measurements of draught were carried out in 18 buildings at 36 work sites[35] and the number of unsatisfied persons to local thermal conditions was evaluated by using the international standard ISO 7730[36]. Draft rating index is:

$$DR = (34 - t_a) * (v - 0.05)^{0.62} * (0.37 \cdot v \cdot Tu + 3.14)$$

$t_a$ is an ambient temperature
$v$ is a local air velocity
$Tu$ is a local intensity of turbulence of air flow.

In terms of the DR-index, nearly 80% of the work sites

**Table 2. The operative temperature at different heights with and without heaters**

| | | Operative temperature, ˚C | | Heat flux from skin, W/m$^2$ | |
|---|---|---|---|---|---|
| Height | Object | Without | With heaters | Without | With heaters |
| 1.7 m | Head | 5.1 | 12.8 | 125 | 72 |
| 1.4 m | Shoulders | 4.8 | 12.0 | 91 | 46 |
| 1.1.m | Hands | 5.4 | 11.9 | 118 | 86 |
| 0.1 m | Feet | 4.3 | 7.1 | - | - |

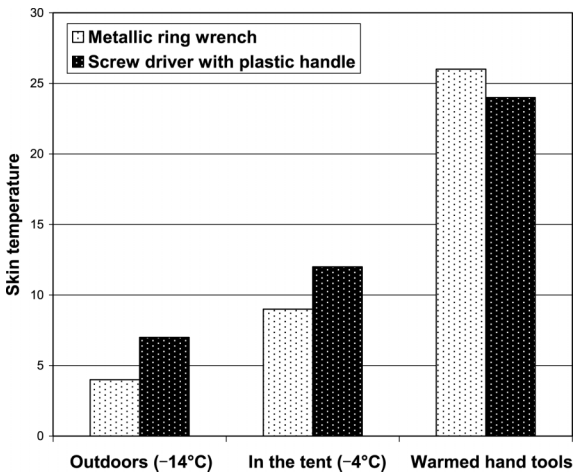


**Fig. 4. Skin temperature of fingers in different circumstances.**

at the doorline were draughty when the large door was open, regardless of an air curtain. At worst, the thermal conditions in the doorway were even harsher than outside the doorway, as strong outdoor airflow cools the body efficiently. However, the difference at workplaces with or without air curtains at large doorways can be even 10˚C measured with a wind-chill-index. Even though the protective effect of the air curtains was not enough to create pleasant working conditions at doorway and doorlines, the air curtains significantly decreased the temperature fluctuations at the work sites.

The discomfort due to using large doors was emphasized in small, narrow halls, and the situation often became similar as the number of doors increases. Permanent draught due to the use of large doors can be created as a result of the slow recovery of thermal conditions during heating season. By preventing cold air flows at the doorway, more comfortable working conditions, as well as significant saving of energy, can be achieved. When planning out the operations and the work sites, the doorway and the doorline should be noticed as draught risk areas[37]. Fixed work sites for permanent work should be located far away from the doorline areas and no work sites should be placed at the doorway area, because there the thermal conditions can be even worse than outside.

Energy loss was reduced by over 80% compared with the open doorway. But not only for economical reasons, but also the discomfort, health and even occupational accident risk demand better working conditions relating to draught.

## Discussion

The cold environment indoors and outdoors has not received much attention in safety research even though there are many millions of outdoor workers in Arctic areas and the circumstances vary a lot in outdoor work. The work environment can be defined to be the accident cause or contributing factor in the accident situation. The incidence rate of accidents was shown to be higher in activities which are carried out, at least partly, outdoors compared to indoor work. The most serious accidents occur when moving a lot in natural outdoor conditions especially when the climate is cold enough or changing a lot[7]. Generally it is assumed that it is difficult or even impossible to prevent occupational accidents in changing conditions outdoors. However many prevention experiments have shown that it is possible to develop preventive measures for natural outdoor conditions, quite many of them are accepted in use and the measures have a clear influence on the accident rate[7]. The measures should be directed to work area, slippery surfaces, working in the heights as well as tools, equipment and machinery as was shown[25].

Management and control of cold related health, performance and safety risks should be integrated comprehensively to the company's policies, to the company's occupational health and safety management system. Further, evaluation of cold related adverse effects is an important aspect to take into account when estimating costs and benefits. By using standard, OHSAS 18001, it is easy to find guidelines for preventive measures and management of cold related risks based on the principal of continuous improvement[26]. Hence, risk management and prevention of cold have effects on safety and well-being in workplaces.

In addition, cold risk management has effects on productivity and costs. Working in the cold has been esti-

mated to increase the personnel costs in the construction industry by 3%[39]. But it is possible, and financially profitable, to reduce these costs by preparing a cold work plan for each construction site operating during the winter. According to the study, this should be part of the site's safety plan and should record all the measures, responsibilities and timetables required for good risk management under cold conditions.

Nowadays, when the climate change is an actual issue, it would be interesting also to find out, how much the wind shields and tents reduce energy consumption, cooling of workers and accident risk e.g. in the construction industry.

As the conclusion we can state that nowadays we use too seldom technical means to protect against cold conditions. By improving our risk management in cold conditions we could not only better preserve our health and reduce accident risks but also improve our work performance and energy savings.

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