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Risk Management of Working in Cold Environments

A Scoping Review

ABSTRACT Millions of people are exposed to cold environments daily. Adverse health risks are prominent for outdoor and cold storage workers. Therefore, a systematic risk management approach is highly motivated. This scoping review aimed to describe the current knowledge regarding risk management of cold exposure hazards in the occupational setting. We also examined differences between sexes in risk management practices regarding cold exposure.

The review included 25 peer-reviewed papers from 1980 to current in English and the Nordic languages, which could be divided into two categories: risk assessment and risk treatment. The risk assessment category included 17 papers, which investigated specific topics such as personal protective equipment, models for thermal balance, and individual differences regarding sex and body mass index. The risk treatment category included eight peer-reviewed papers, which emphasised the use of different protective or preventive measures and highlighted the importance of successful implementation and improvement of good practices.

To conclude, the previous literature on risk management of cold work was mainly oriented around technical risk assessment. However, there seems to be a lack of knowledge regarding implementation, resulting in inadequate protection for workers. Moreover, research was scarce regarding sex-dependent differences in risk management among workers exposed to cold.

KEYWORDS cold climate, working conditions, protective measures, primary prevention, implementation science, occupational health, risk assessment, protective clothing, legislation

Introduction

Millions of people are daily exposed to cold environments (Kummu & Varis 2011), and around the world, most of all temperature-related deaths are due to cold exposure (Friedman et al. 2020). According to international standards, cold work can be defined as occurring in ambient air temperatures at or below 10°, or when a person has cold-temperature-related symptoms (ISO 15743:2008; Mäkinen et al. 2006). The physical properties of cold environments are also defined in ISO 11079:2007. The main source of cold exposure in everyday life is low ambient temperatures, mostly outdoors during wintertime. Outdoor workers, such as construction workers, traffic controllers, postal workers, as well as child and elderly care staff are especially exposed during the winter season (Swedish Work Environment Authority 2022). In addition, occupational cold exposure also occurs indoors when working in cold rooms for food preparation and storage. External factors that also need to be considered include contact with cold objects and the effects of moisture and wind (Mäkinen & Hassi 2009; Stjernbrandt 2021). It is common, globally, to work in cold environments between 0 and 10 °C, thousands work in cold rooms below −25 °C and some industries even require temperatures between −40 to −50 °C (Ikäheimo et al. 2021). When exposed to cold, our body exerts numerous physiological responses triggered by decreasing skin temperature in the form of adjustments in peripheral circulation, shivering, and metabolic changes (Bjertnaes et al. 2022). Moreover, our experience and responses to cold are not only affected by external environmental factors, clothing, and activity (Stjernbrandt 2021) but also physiological factors, such as age, sex, fitness level, body size, health, and acclimatisation (Castellani & Young 2016; Gavhed 2008; Holmer 1993; Ikäheimo et al. 2021; Stocks et al. 2004).

Cold exposure evokes physical responses (e.g., respiratory, circulatory, dermatological, musculoskeletal, and cardiovascular) (Bjertnaes et al. 2022; Mäkinen & Hassi 2009; Parsons 2021). It could also change our psychological responses, such as cognitive abilities and performance, disposition, perceived comfort, and subjective experiences of cold (Falla et al. 2021; Giesbrecht et al. 1993; Parsons 2021). This could lead to a variety of behavioural changes, such as altered physical activity, risk behaviour, and decreased productivity (Havenith, Heus & Daanen 1995; Ikäheimo et al. 2021). Health effects from cold exposure can vary in severity and within occupational settings it can lead to disabilities and injuries. Longer periods of cold exposure increase cognitive stress and risk behaviour, which directly increases the risk of accidents (Hassi et al. 2002).

A systematic work-environment management approach should be used to ensure safe working practices and to maintain the well-being and health of employees. This approach is supported by the international standard for risk management which includes "setting strategy, achieving objectives and making informed decisions" (ISO 31000:2018:V). The outcomes within the risk management approach should be cost-effective, scientifically sound, integrated actions that "treat" risks while considering social, ethical, cultural, political, and legal considerations. Just as with the systematic work-environment management approach, the aim is to reduce or prevent risks. Identification, analysis, and evaluation of risk constitute the concept of risk assessment (ISO 31000:2018). Assessing cold exposure serves several purposes such as maintaining comfort, reducing the risk of adverse health effects, and increasing performance and productivity (Holmér 1993). For this purpose, cold risk assessment models, methods, and ISO standards have been developed. For instance, the ISO 11079:2007 standard can be used for the determination of cold stress, required clothing insulation (IREQ) and local cooling effects. Additionally, there are health surveillance questionnaires, thermal comfort assessment methods, and tools for calculating an appropriate exposure duration (Hassi, Raatikka & Huurre 2003; ISO 15734:2008; Mäkinen & Hassi 2002).

Depending on the type of work, activity, and subjective experiences about cold exposure, flexible solutions to protect personnel are required, and will therefore differ between workplaces (Gavhed 2008). To be able to advance the knowledge about health risks from cold exposure, together with risk assessment and management of the hazards from cold work, a systematic review was initially intended. However, due to the heterogeneity within this research field, this approach was not feasible. A scoping review was therefore launched, aiming to map concepts, evidence, and gaps within this research field.

The primary aim of this scoping review was to describe the current knowledge regarding risk management of cold exposure hazards in the occupational setting. The secondary aim was to examine whether there were differences between sexes in risk management practices of cold exposure.

Methods

This scoping review was performed using the PRISMA ScR extension (Tricco et al. 2018). A systematic literature search string was developed and performed on 16 January 2023 (Supplementary data 1). The search strings defined the context to be "cold environment" with the concepts "work-related" and "risk planning." The search was limited to the years 1980 to current (2023). We included papers in English, Swedish, Finnish, Norwegian, and Danish. The search was performed in the following databases: Ovid MEDLINE and In-Process & Other Non-Indexed Citations and Daily (1,765 references), Embase Classic + Embase (2,249 references) and Web of Science, Core Collection (4,764 references). We used the controlled vocabulary of the Medical Subject Headings (MeSH) from MEDLINE, and the Emtree thesaurus from EMBASE, when applicable. In addition, the search fields title, abstract, and keywords were searched. All references were exported to Endnote TM (97.4; Thompson Reuters, Toronto, ON, Canada), removing any duplicates (1,767 references). All unique references were imported into the Covidence systematic review software (Veritas Health Innovation, Melbourne, Australia), an online tool for screening references. A list of objective inclusion criteria was developed and made available for all reviewers participating in the blinded screening process.

For papers to be included, all outlined key concepts needed to be included (cold environment, work-related, and risk planning). Articles focusing on animals or technical systems (that did not specifically relate to human health) were excluded, as well as theses, reviews, expert opinions, books, letters, workshops, editorials, and conference proceedings. The first stage included voting (yes/no/maybe) based on title and abstract. The default setting was that each reference got two blinded votes. If the opinions of these two reviewers diverged, conflicts were solved by a third reviewer's vote or by discussion until a consensus was reached. During this stage, 46 more duplicates were found and removed. From the 6965 references, 250 voting conflicts in the team occurred. A total of 273 abstracts were chosen for full-text evaluation, and this process was conducted with the same procedure as above.

The importance of the management perspective was emphasised. If a paper was solely about cold exposure in relation to a health effect, it was excluded, as it did not have a management or preventive perspective. After the first full-text review, 96 papers were considered, and three categories deviated from the original aim: military studies, disaster medicine papers, and laboratory studies. These were subsequently excluded. For the remaining 30 papers, references were scanned for any additional publications that had not been found in the original search. Three additional papers were found, resulting in 33 papers considered for this review. In this final round, all papers were once again screened in full text, with a specific focus on the study population. Another 8 papers were then excluded as they did not fulfil the inclusion criteria. In total, 251 papers were excluded in the eligibility stage, leaving 25 papers included in this review (Fig. 1). Since this scoping review was limited to studies of published literature, ethical approval was not required.

Results

A total of 25 peer-reviewed papers were included in this review from the years 1988 to 2022 (Table 1 and Fig. 2). About half (N=13; 52%) were published within the past 10 years. Roughly two-thirds (N=16; 64%) were of descriptive design, reporting on cold exposure or the use of risk management models or assessments. The remaining were either mixed methods or experimental designs where new models, tools, or software were developed and implemented. The most recent data collection was conducted in 2013 (Jussila et al. 2017; Reiman, Sormunen & Morris 2016). However, more than half of the papers (N=14; 56%) had not stated when data was collected.

About half the articles (N=11; 44%) included study populations exposed to indoor artificial cooling, mostly workers within food processing industries. Outdoor workers were exposed in various construction jobs, outdoor delivery services, forestry, or worked as travel guides, machine operators, or engineers. The largest study sample contained 1,323 participants (Jussila et al. 2017) whereas the smallest had 14 participants (Soares 2012). Almost two-thirds (N=15; 60%) of the papers specified the number of men and women participating. Three of the papers (Oliveira, Gaspar & Quintela 2008; Tirloni et al. 2018; Tirloni et al. 2017) included mostly female participants who were occupied either in food processing or supermarkets. Four of the papers (Anttonen & Virokannas 1994; Golbabaei et al. 2022; Inaba, Kurokawa & Mirbod 2009; Naesgaard et al. 2017) had study populations consisting of only men, working in the petroleum industry, construction, or as traffic controllers, postal workers, patrol skiers or reindeer herders. The environmental settings varied largely, from outdoor temperatures of −30 °C with high humidity and windspeed, to indoor temperatures of 15 °C.

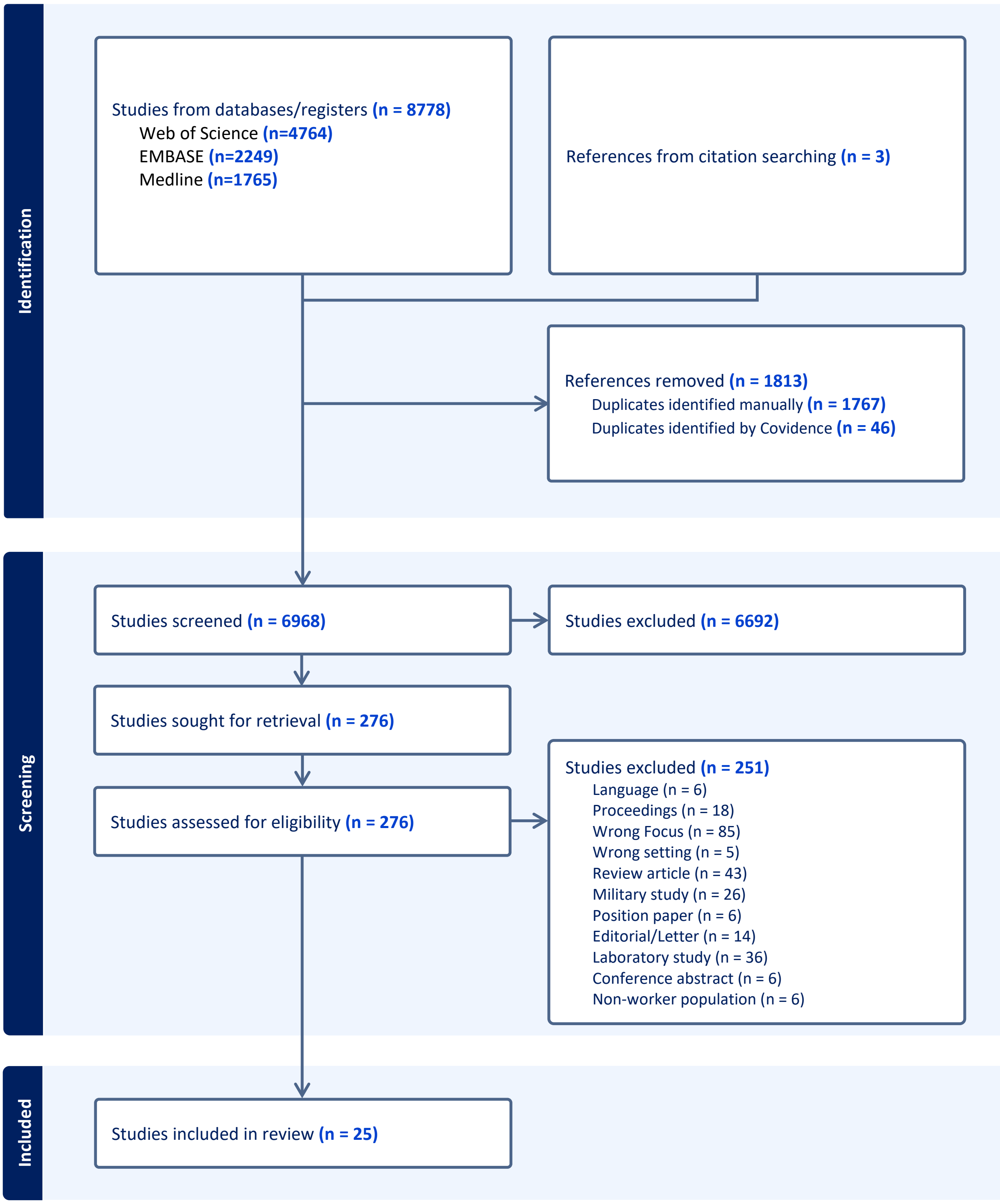

Fig. 1. PRISMA flowchart for the literature search and inclusion of articles in the scoping review.

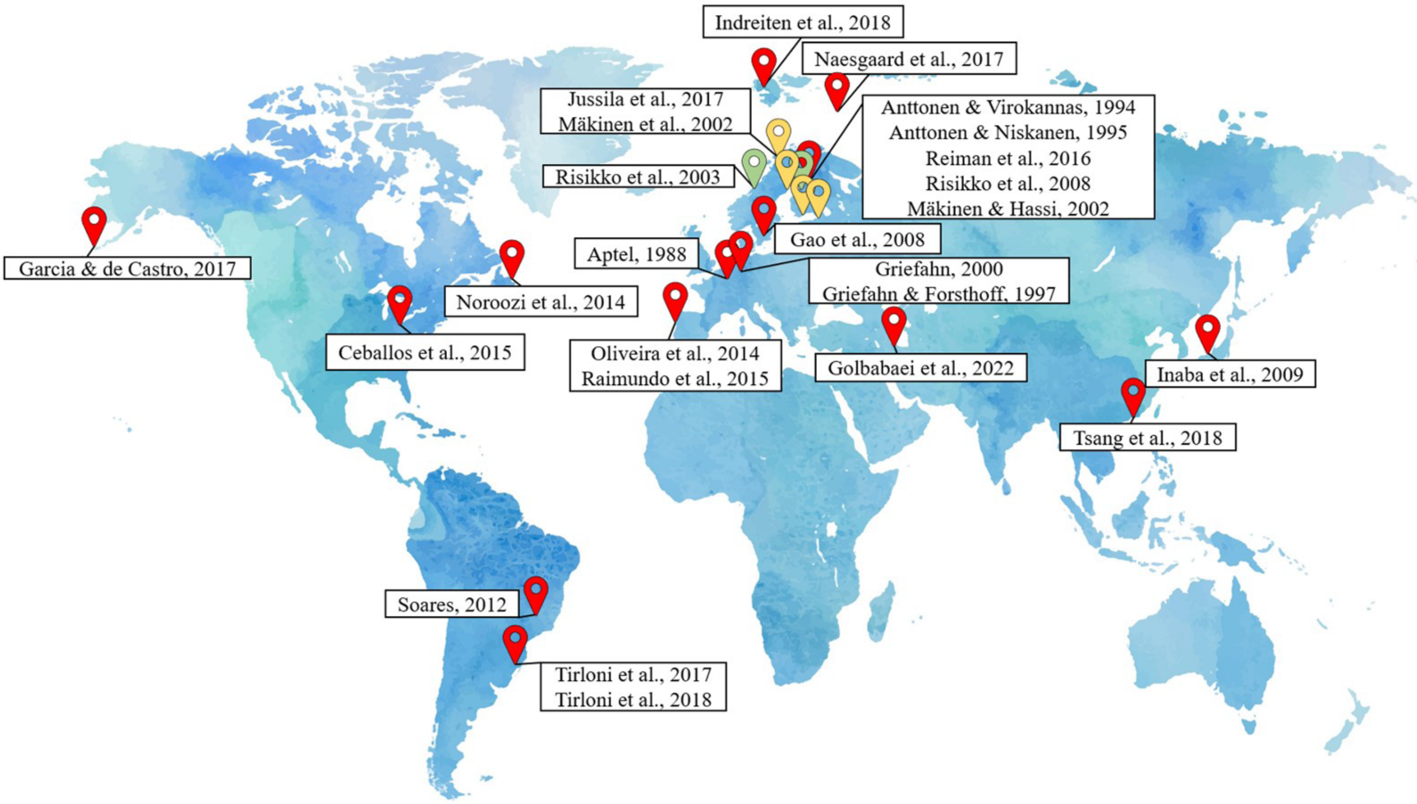

Fig. 2. Geographical distribution of study population origin. Yellow/Green marks = Collaboration across borders.

The aims and outcome focus of the included 25 papers varied within the broad concept of risk management of cold exposure. With guidance from the concept definitions in ISO 31000:2018 two broad categories could be identified: “risk assessment,” which refers to the identification of problems, and “risk treatment,” which entails the subsequent process when cold-related issues have been identified. A description of the papers and the classification into risk assessment (Table 1.1–1.2) or risk treatment (Table 2) are presented in Table 1.

Risk Assessment

Identification, analysis, and evaluation of risk define the concept of risk assessment (ISO 31000:2018). By using a systematic approach to identifying and understanding the complexity, character, and capacity of risk, the decision-making process is supported to develop strategies for reducing or eliminating risks. A total of 17 papers were included in this section and further divided into subgroups of different risk assessment focuses.

Table 1. Included papers. Descriptive information

Reference	Aim	Design	Occupation(s)	Sex	Environmental setting	Target group	Conclusion table
Anttonen & Niskanen (1995)	To develop a planning guide for local infrared heating systems and to compare the results to the heaters in the workplace	Experimental—intervention study without a control group	Workers in a meat and sausage packing factory	Not specified	Artificially cooled indoor environment (5 °C)	Management	2
Anttonen & Virokannas (1994)	To assess and evaluate the cold stress of outdoor workers in wintertime in Finland and the need for changes in the strategies for occupational health and safety	Descriptive—measuring existing exposure	Patrol skiing (N=8), road construction work (N=10), surveying work (N=8), railway yard work (N=8), reindeer herders (N=9), electrical fitters (N=10), postmen (N=18), geological drillers (N=9), forest machine repair (N=35), cold indoor work (butchers, wood milling, food processing and fishermen; N=15)	M=143	Winter outdoor settings (6 to −29 °C)	Management	1.1
Aptel (1988)	To determine if the thermal insulation of the provided clothes and clothes chosen to be worn by workers was sufficient	Descriptive—evaluation of workers' current clothing isolation and if they could evaluate their own insulation needs	Workers in slaughterhouses or cold stores, butchers, and storekeepers	Cold room group: M=21; cool room group: M/F=33 (not further specified)	Artificially cooled indoor environment (−30 to 10 °C)	Management	1.1
Ceballos, Mead & Ramsey (2015)	To describe work conditions and provide recommendations for thermal comfort and prevent safety and health problems for cold room employees at an airline catering facility	Descriptive—case study	Cold room employees at an airline catering facility	Not specified	Artificially cooled indoor environment (around 4 °C)	Management	2
Gao, Holmér & Abeysekera (2008)	To collect information on slips and falls on ice and snow and associated injuries, assess risks of various icy and snowy surfaces, identify design needs for footwear, and ascertain outdoor worker preferences for preventive measures	Descriptive—measuring existing exposure	Newspaper delivery service, northern military regiment, mining, and construction in northern Sweden	Newspaper: M=38, F=28; military: M=39, F=1; mining: M=52; construction: M=24, F=1	Outdoor winter season in northern Sweden	Management and product developers	1.1
Garcia & de Castro (2017)	To explore the types of problems among Filipino fish processing workers in an Alaskan community	Descriptive—using qualitative methods	Fish processing, handling frozen products	M=20, F=6	Northern Alaska, both indoors and outdoors, freezing temperatures	Management	2
Golbabaei et al. (2022)	To clarify the impact of cold environmental exposure on employees working at an oil transfer facility in northwestern regions of Iran	Descriptive—cross-sectional study	Workers at a petroleum transfer station	M=36	Outdoor temperatures, (daytime −20 to 5 °C, nighttime −24 to 4 °C)	Management	1.1
Griefahn & Forsthoff (1997)	To analyse differences between estimated and calculated clothing insulation for workers exposed to air temperatures between 0 and 15°C	Descriptive—technical note—measuring exposure	Daily cold-exposed workers, meat processing (N=24), distributors (N=11), brewery workers (N=4)	M=33, F=6	Indoor temperatures (0 to 15 °C)	Researchers, and management	1.1

Griefahn, (2000)	To determine if the IREQ model has applicability limitations and possible ways to improve it	Descriptive—field study	Daily cold exposed workers: meat processing (N=47), distributors (N=16), brewery (N=4), dairy industry (N=5) and chemical industry (N=3)	M=59, F=16	Indoor temperatures (0 to 15 °C)	Management	1.1
Inaba, Kurokawa & Mirbod (2009)	To compare cold prevention measures and subjective symptoms between construction workers and traffic control workers during wintertime	Descriptive—comparative study	Traffic control workers and construction workers	M=247	Outdoor winter conditions (3 to 9 °C)	Management	1.1
Indreiten, Albrechtsen & Cohen (2018)	To exemplify how experienced feedback and tacit knowledge are used to manage safety for operations in the high Arctic and discuss how experience feedback can ensure organizational learning for field operations	Descriptive—case study	University field workers, students, and field technicians during snowmobile and boat travels.	Not specified	Winter: avalanche terrain, sea ice, glaciers, harsh weather conditions; Summer: harsh weather, rough oceans, mountain terrain	Management	2
Jussila et al. (2017)	To investigate Arctic open pit mine workers' protective strategies against cold within working environments, and to assess the sufficiency of chosen protective clothing	Descriptive—questionnaire study	Open-pit mine workers	M=1211, F=112	Outdoor climate, mild or wet cold (−5 to 5 °C); dry cold (−20 to −10 °C)	Management and employees	1.1
Mäkinen & Hassi (2002)	To evaluate the usability of the ISO thermal standards, as well as to evaluate the need for training of workplace and occupational health and safety personnel in the use of these methods	Experimental—Observing work, and testing the usability of the thermal standards	Construction work; bricklayers, assistant bricklayers, reinforcing bar placers, mounters of prefabricated units, and supervisor of channel maintenance (seafaring)	Not specified	Outdoor work	Management, employees, and OHS staff	1.2
Mäkinen et al. (2002)	To elaborate a model and set of methods for the assessment and management of risks specifically associated with cold exposure at work and to improve knowledge about cold conditions among the staff of the participating companies	Experimental—testing new methods for risk assessment and management	Construction work (Finland, Sweden), forestry (Sweden), road maintenance (Sweden), and fish processing (Norway)	Not specified	Mostly outdoor work, indoor settings for fishery. Not specified temperatures or other factors	Management, employees, and OHS staff	1.2
Naesgaard et al. (2017)	To describe a user-centered design process for new personal protective clothing for petroleum workers operating on offshore installations in the Barents Sea	Mixed—innovation project including elements of participatory and user-centred design	Petroleum workers	Not fully specified. Cold chamber testing: M=6	Outdoor maritime conditions, between 0 to −30 °C)	Employees	2
Noroozi et al. (2014)	To suggest a novel methodology that emphasises how cold and harsh environments affect human performance	Experimental—testing a developed method	Offshore oil and gas facilities, operators, and engineers	Not specified	Not specified, Arctic and subarctic regions	Policymakers	2
Oliveira et al. (2014)	To characterize the working conditions in the food distribution sector regarding cold environments	Descriptive—field report	Supermarket staff, workers in freezers and refrigerated rooms, free-floating or controlled air temperature manufacturing workplaces	71 % women (translates to M=47, F=113)	Artificially cooled indoor environments, freezers (−10 to −20 °C); refrigerated rooms (0 to 10 °C); manufacturing workplaces (10 to 15 °C)	OHS staff, management, and government	1.1

Raimundo et al. (2015)	To assess cold stress in the food industry, particularly in freezing chamber working environments, and the achievement of useful guidelines for improvements	Descriptive—field study	Food industry workers, workers in freezers	Not specified	Artificially cooled indoor environments	Government and management	1.1
Reiman, Sormunen & Morris (2016)	To create an evaluation tool for heavy mining in arctic environments both for operator well-being and vehicle performance	Mixed—deductive approach of participatory ergonomics, observations. literature review and development of an OHS management checklist	Workers in an open pit mine, heavy mining vehicle operators	Not specified for miners: Observers: M=5, F=3	Outdoor winter season, northern Finland	Management and OHS staff	1.2
Risikko et al. (2003)	To create a cold risk management model for the workplace environment and to evaluate its practicality	Experimental—developing and assessment of a new model	Construction, food processing, airport personnel, fishing, and maintenance workers in the offshore oil industry	Not specified	Outdoor (construction work): wind, rain, snow, and icy surfaces; indoor (fish processing): 10 to 13 °C at feet level; 22 to 24 °C at head level; 6 to 7 °C for handled foodstuff	Management and OHS staff	1.2
Risikko, Remes & Hassi (2008)	To evaluate the implementation of cold risk management in Occupational safety and health practices at the Finnish Maritime Administration (FMA) and the effects of the development and implementation	Mixed—evaluating implementation	Maritime outdoor workers, pilots, channel and vessel personnel	Not specified	Outdoor maritime work	Management	2
Soares (2012)	To investigate the issue of the non-use of PPE (personal protective equipment) in a trading company of chilled and frozen food products	Descriptive—case study	Supermarket staff	M=10, F=4	Artificially cooled indoor environments: fridges, freezers, cold storage, and contact with cold products	Management	1.1
Tirloni et al. (2017)	To evaluate the temperature of the hands and its relationship with the thermal sensation of the hands and the use of a cutting tool in pig slaughterhouse workers	Descriptive—measuring exposure	Workers at a pig slaughterhouse	M=47, F=59	Artificially cooled indoor environments (8 to 12 °C)	Management	2
Tirloni et al. (2018)	To analyse the finger temperatures of the poultry slaughterhouse workers, and their association with personal and organizational variables, bodily discomfort perception, and thermal sensation of cold	Descriptive—measuring exposure	Poultry slaughterhouse workers	M=34, F=109	Artificially cooled indoor environments (9 to 12 °C); handling foodstuff (1 to 11 °C)	Government and product developers	1.1
Tsang et al. (2018)	To suggest an Internet of Things-based risk monitoring system designed to manage, real-time monitor, and assess product quality and occupational safety risks within cold chains	Experimental—testing a monitoring system integrated with a fuzzy logic approach	Suppliers, processes, distributors, and retailers for handling environmentally sensitive products, handling frozen meat, and seafood	Not specified	Cold chain work, freezing (−25 to −18 °C); chilling (0 to 8 °C)	Management	1.2

IREQ: Required Clothing Insulation; ISO: International Organisation for Standardisation; OHS: Occupational Health Services; M: Male; F: Female

Evaluation of Personal Protective Equipment (PPE)

Twelve papers (Table 1.1) evaluated personal protective equipment (PPE) and in general came to the same conclusion: the provided PPE (clothes, gloves, and footwear) did not sufficiently protect the workers from thermal discomfort or risks of cold-related health problems. An additional four papers (Anttonen & Niskanen 1995; Ceballos, Mead & Ramsey 2015; Naesgaard et al. 2017; Tirloni et al. 2017) focused on workers' thermal comfort and how different protective measures would be helpful.

Table 1.1. Evaluation of PPE

References	Conclusion
Anttonen & Virokannas (1995)	Performance decreases in cold conditions for light work from 10 °C, and adverse health effects occur from −6 °C. Protective clothing and health examinations should be evaluated. Practical and systematic evaluation methods should be used to prevent adverse health effects.
Aptel (1988)	Workers can evaluate their own needs in thermal clothing insulation with enough accuracy if the IREQ is under 1.5 clo. For workers where the IREQ is higher than 1.5–2 clo, it was difficult to increase their thermal insulation by adding garments.
Gao, Holmér & Abeysekera (2008)	Fall events occur most frequently on ice covered with snow. This is due to the difficulty of perceiving hidden risks to adjust gait strategies. The provided footwear was not sufficient protection against slips and falls. Slip prevention was mostly performed using anti-slip materials, such as salt or sand.
Golbabaei et al. (2022)	The available clothes are not sufficient to protect against the general whole-body cooling for long-term exposure. Sufficient hand function was compromised, with a temperature below 15 °C on some working days, putting them at risk of local cold injury. Face and finger temperatures dropped rapidly at 10 °C with wind. Almost all study participants stated that the winter season was the most challenging time to work. Many did not use personal protective equipment when in contact with cold objects below 0 °C, increasing the risk of local cold injuries. The authors conclude that current practices are not sufficient.
Griefahn (2000)	The IREQ model is applicable for air temperatures up to 15 °C but needs to be improved concerning sex. The model was primarily developed and validated for male subjects. High activity rates together with individual variations cause serious clothing problems as frequent adjustments during shifts can be impossible. A more even workflow, avoiding high and low activity combinations, is therefore the only solution.
Griefahn & Forsthoff (1997)	The estimated clothing insulation (of clothes worn) was significantly higher than the calculated requirement (according to IREQ). This discrepancy was related to time adjustments for the metabolic rate of single activities especially when temporarily exposed to different temperatures. (Saw differences in those working temporarily at 13 to 15 °C and those who always did). This would indicate that the IREQ model validation limits to between 7 to 13 °C. (Holmér presented cut-off at 10 °C).
Inaba, Kurokawa & Mirbod (2009)	Windchill index was used to measure objective cooling and there were no significant differences in cooling, pain, or numbness between traffic control workers and construction workers. Traffic control workers more often wore warm protective clothing than construction workers, due to high physical workload. Both groups were at risk of disorders due to their working environment (not having sufficient PPE) and there was a need for occupational health programs for the prevention of cold exposure disorders.
Jussila et al. (2017)	Arctic open-pit miners chose clothes ensembles depending on occupational (time outdoors), environmental (moisture, temperature, wind) and individual factors (cold sensitivity, general health). However, the selected clothing was not sufficient to completely prevent cooling at ambient temperatures below −10 °C. Reasons may be that heavy clothing restrict movement, compatibility issues with the use of several PPE at the same time or rapid changes in work tasks and physical load. Employers should provide sufficient cold protective clothing and guidance for the workers.

Oliveira et al. (2014)	The incidence of adverse health effects was higher among women. For a substantial percentage of the workers, the available clothing ensembles were inadequate for the environmental conditions, resulting in more difficulties in performing activities during the winter. An analysis focusing on sex showed that women experienced feeling more cold thermal discomfort and having less tolerance to cold conditions.
Raimundo et al. (2015)	The clothing ensembles normally used by the workers did not provide the minimum required insulation for the current exposure. Periods of exposure were too long and recovery periods too short, leading to physiological strain.
Soares (2012)	Staff was not wearing sufficient PPE as it is barely acknowledged by anyone. The supervisor instructed workers on the proper use of PPE, but follow-up was not performed. The company needed to take action to fulfil minimum legal requirements, including frequent training sessions, creating awareness, and instructing staff on how to use PPE properly.
Tirloni et al. (2018)	Most workers presented at least one finger with an average temperature ≤15 °C, perceived cold hands, and wore three layers of gloves on each hand. Hand tool use increases the probability of feeling cold. Protective gloves need improvement.

Ten papers (Anttonen & Virokannas 1994; Aptel 1988; Golbabaei et al. 2022; Griefahn 2000; Griefahn & Forsthoff 1997; Naesgaard et al. 2017; Oliveira et al. 2014; Raimundo et al. 2015; Tirloni et al. 2017; Tsang et al. 2018) used the required clothing insulation (IREQ) model within their research and analysis. Three of these (Aptel 1988; Griefahn 2000; Griefahn & Forsthoff 1997) were fully devoted towards refining and understanding this model. Aptel (1988) found that workers could attain enough thermal insulation without guidance if the need for thermal insulation was 1.5 clo or less (0 to 10 °C). Griefahn and Forsthoff (1997) found that workers wore clothes with higher insulation than suggested by IREQ. Griefahn (2000) concluded that the IREQ model could be used for air temperatures up to 15 °C and that most workers seemed to overestimate the need for insulation systematically. The reason could be that employees rarely replaced the frequently worn and rarely washed protective clothing, leaving the clothing insulation reduced (Griefahn 2000).

Tirloni et al. (2018) concluded that even though workers in a slaughterhouse used approved gloves, and several layers of gloves on each hand, the majority (77.9%) experienced cold hands in temperatures ≤ 15 °C. Two studies (Jussila et al. 2017; Raimundo et al. 2015) found that workers preferred to wear lighter, less restrictive clothing and be able to leave the cold workplace when they felt discomfort rather than to wear the recommended or sufficient insulation. Oliveira and colleagues (2014) pointed out that workers not provided with or using PPE were able to spend less time in adverse thermal environments. This leaves workers in need of longer and more frequent thermal breaks. However, results by both Raimundo et al. (2015) and Oliveira et al. (2014) found that almost half of all workers had no rest periods, and only 6% and 12% had more than 30-minute breaks, respectively.

Three papers (Aptel 1988; Garcia & de Castro 2017; Soares 2012) presented a discrepancy between what "should be" and "what is" regarding risk assessment of cold exposure. Garcia and de Castro (2017) and Soares (2012) concluded that although labour legislations are clear regarding the obligatory use of PPE, the management regulations, and policies regarding PPE and what happened on the floor were not in line.

Soares (2012) highlighted that employees expressed a lack of training and knowledge to be able to use PPE properly and that these were not available nor used due to the equipment being uncomfortable. Aptel (1988) showed that workers usually wore their own clothes, and most women only covered 60% of their body due to the use of skirts or dresses, with no extra protection for the head and hands even if PPE covering 95% of the body was provided by the employer.

Six papers (Gao, Holmér & Abeysekera 2008; Griefahn 2000; Inaba, Kurokawa & Mirbod 2009; Jussila et al. 2017; Oliveira et al. 2014; Tirloni et al. 2018) studied differences between participants regarding sex and body mass index (BMI) while working in cold. Gao and colleagues (2008) concluded that the most frequent occurrence of injuries (slips, trips, and falls) was on ice covered with snow, and there was no statistically significant difference between men and women, but difficulty in perceiving hidden risks. Jussila et al. (2017) and Inaba, Kurokawa and Mirbod (2009) both reported that workers with low or normal BMI (<25 kg/m²) selected higher clothing insulation, compared to workers with higher BMI, who appeared to have better natural insulation, giving them more efficient protection from cold exposure. Jussila et al. (2017) also found that female workers would select warmer clothing in dry cold conditions than men to be able to maintain thermal comfort, and Oliveira et al. (2014) concluded that women classified their work as more physically demanding than men, had a higher risk of detrimental health effects and felt colder and tolerated less cold than men. Tirloni et al. (2018) concluded that the provided PPE was not suitable for individual differences in fit and size, which made it harder for women to find appropriate protection. Griefahn (2000) emphasised the importance of improvement regarding sex aspects. The results confirmed that women had significantly lower clothing insulation for the same thermal conditions as their male colleagues. This limits the applicability of the current IREQ model, which does not consider sex.

ISO Standards and Method Development

Five papers (Table 1.2) had the main purpose of evaluating, developing, or proposing new assessment methods and ISO standards. Mäkinen et al. (2002) stated that ISO standards have been produced to assess the risk of thermal environment, but no instructions on how to apply them in practice have been described. Therefore, a three-step model was developed and practically tested, including a general health questionnaire, interviewing workers to find more in-depth limitations, and medical screening by occupational health and safety (OHS) personnel and health experts. Reiman, Sormunen and Morris (2016) on the other hand, developed a holistic evaluation tool for well-being in the Arctic mining environment, suggesting that the current tools were insufficient due to the increasing number of women in a previously male-dominated industry. Tsang et al. (2018) developed an artificial intelligence (AI) tool using fuzzy logic to assess product quality and occupational safety risks in cold chain activities. This study concluded that the developed user-friendly AI application would help management in decision-making processes to maintain the desired quality of products and reduce health risks and accidents.

Table 1.2. ISO standards and method development

References	Conclusion
Mäkinen et al. (2002)	The method was tested, and results showed that practical methods are needed in occupational settings to identify cold-related problems at work. Two- and three-step models were produced and assessed. A checklist was created to identify cold-related hazards.
Mäkinen & Hassi (2002)	To test the usability of the cold risk assessment methods from the different ISO thermal standards evaluations were done in two stages depending on the complexity, duration and need for expertise. Stage 1 tested workplace assessments, including observations and simple measurements. Results showed that the training provided was sufficient for performing this part of the assessment. Stage 2 was more laborious to perform, and conclusions were made that the provided training at this stage was not entirely sufficient, which was mostly related to difficulties in analysing the results.
Reiman, Sormunen & Morris (2016)	A systematic checklist was developed and evaluated, including sections for evaluating vehicle-specific ergonomic and safety aspects from a technological point of view and for checking if the work was arranged to be performed safely and effectively from an employee's point of view. Categories included working outside the cab (access, daily checks, refuelling), working inside the cab (size and design) and assessment of workload (physical, psychosocial, and social).
Risikko et al. (2003)	The developed method for cold risk assessment and management was easy to use after a one-day training session, and trained professionals could identify cold-related risks and preventive measures. The checklist and the cold work plan worked well. They were partially overlapping.
Tsang et al. (2018)	An Internet of Things based risk monitoring system for managing cold supply chain risks were developed and tested. Showing to provide a good foundation for identifying product quality and occupational safety risks. Workers' satisfaction and efficiency was improved, and cold-related accidents and injuries are reduced.

Two papers (Mäkinen & Hassi 2002; Risikko et al. 2003) focused on the usability of developed risk assessment methods, emphasising their importance. Risikko et al. (2003) stressed that having a usable and inexpensive cold risk management model would help employers follow international and national OHS legislations and norms. The results of the study by Mäkinen and Hassi (2002) showed that 88% found the use of written instructions and training adequate to identify cold-related hazards. However, when more in-depth risk analyses were needed at the workplace, most (62%) found that the assessment methods were unclear and very time-consuming. The study by Risikko et al. (2003) suggested that for a risk management plan to be successful, all responsible functions need to be named and familiar with the material, and plans should be documented in a written format to ensure the possibility of follow-up.

Risk Treatment

The objective of risk treatment is to select and implement suitable actions for addressing the assessed risk. To balance costs and benefits, the chosen methods need to be monitored, as well as quality, effectiveness, outcomes, and possible new risks reviewed (ISO 31000:2018). A total of eight papers had this focus and are presented below (Table 2).

Table 2. Risk treatment

References	Main conclusion
Anttonen & Niskanen (1995)	The use of infrared heaters can increase operative and skin temperature as well as improve thermal comfort.
Ceballos, Mead & Ramsey (2015)	Air draft at workstations, work practices, insufficient use of PPE due to dexterity concerns and lack of knowledge about safety practices, and good health in cold rooms were found as reasons for why cold room employees had thermal comfort concerns. The study presented practical recommendations for improvement.
Garcia & de Castro (2017)	Findings suggested the importance of job rotation to avoid long exposures to cold temperatures, the value of a designated individual to inform workers about company and community resources that promote healthy lifestyles, and the benefits of a joint worker–management safety committee.
Indreiten, Albrechtsen & Cohen (2018)	The authors concluded that to improve knowledge, each technician, system, and practice of experience feedback must be run to ensure individual and organizational learning from both failures as well as successes. The purpose is to use information about experienced or expected safety performance as a basis for decisions that prevent accidents and reduce accident risk. The experience feedback system facilitated systematic improvements in safety. Key concepts were flexibility, resilience (anticipating, monitoring, responding, and learning), and adaptation (context, goals, resources). Organizational learning and knowledge sharing between practitioners, safety staff, and management were also important.
Naesgaard et al. (2017)	Considering user needs and involving the users throughout the design process contributed to new cold-protective clothing with an improved level of user satisfaction. Users needed protection against wind and external moisture, efficient temperature regulation, thermal protection during stationary work, and an unrestricted range of movement. The final product was evaluated in a thermal chamber and found to provide sufficient thermal protection.
Noroozi et al. (2014)	The results showed that the risk value related to the effect of cold and harsh environments on operator cognitive performance was twice as high as the risk value when performed in thermoneutral conditions. The findings confirmed that reevaluating the human error probabilities (HEPs) is required for any scenario in harsh environments and that cold and harsh conditions influence human performance, attention, decision-making, diagnosing, memory, and problem-solving.
Risikko, Remes & Hassi (2008)	Implementation of good practices succeeded well. At the action level, positive changes in concrete cold risk prevention activities were found. However, at the organizational level, there were no improvements in rules and practices. To improve the outcome, implementation goals should be set early, rules, practices, and concrete activities need to be implemented early and visible for improved awareness and motivation. Ownership of the implementation process should be updated with possible organisational changes.
Tirloni et al. (2017)	A significant association could be seen between the thermal sensation and the use of a knife. Workers using a knife felt the coldest. The hand that manipulated the products had the lowest temperatures. Employers should provide gloves with adequate thermal insulation.

Seven of the papers (Anttonen & Niskanen 1995; Ceballos, Mead & Ramsey 2015; Garcia & de Castro 2017; Naesgaard et al. 2017; Noroozi et al. 2014; Soares 2012; Tirloni et al. 2017) emphasised that the different measures for assessing cold-related risks need to be usable and flexible to manage the different types of exposure and associated risks.

Anttonen and Niskanen (1995) showed that a local heater at fixed workplaces was effective in maintaining thermal comfort for the workers. To be able to provide products that are relevant, attractive, and practical for the workers, Naesgaard and colleagues (2017) proposed a user-centred approach where feedback and assessments were conducted by the end-users. Tirloni et al. (2017) emphasised the need for employers to regularly replace PPE as wear and tear decreases their insulation properties and general function. Also, job rotation for the different thermal tasks could be used to increase thermal comfort and performance. In addition, workers' health conditions should be regularly monitored by health professionals. Ceballos, Mead & Ramsey (2015) gave recommendations to a company that had no training or safety policies regarding working in cold rooms. The applied improvements included minimising drafts and time spent inside cold rooms, creating adequate conditions for thermal breaks, providing hand warmers and sufficient PPE, and providing training regarding the hazards of cold exposure. Noroozi et al. (2014) identified psychosocial factors that could improve the work environment in cold workplaces, including emotional stability, teamwork, morale, personal training, and attitudes. They also emphasised the importance of job rotation to reduce long exposure to cold environments. Lastly, they highlighted the value of specific individuals who could inform other workers about company and community resources that promote healthy lifestyles, such as a joint worker–management safety committee, encouraging health and safety training regarding cold exposure. Soares (2012) pointed out that an efficient safety system from policy to practice is essential to be able to create awareness and have frequent training sessions on how to use PPE properly.

Two papers (Indreiten, Albrechtsen & Cohen 2018; Risikko, Remes & Hassi 2008) highlighted the importance of how to successfully implement and improve good practices. Indreiten, Albrechtsen and Cohen (2018) concluded that to ensure constant and safe work performance, a system needs to be in place where experience and feedback are ministered and protected, otherwise the knowledge will disappear together with workers. This concept included a system where experience feedback was transferred from individual knowledge to organisational learning. Flexibility, resilience (anticipating, monitoring, responding, learning), and adaptation (context, goals, resources) were essential key concepts for the systematic management approach. To make structural changes, constant feedback (positive and negative) from the fieldwork and the opportunity to gain experience from each other was needed. The study by Risikko, Remes and Hassi (2008) showed that the quality and availability of PPE, access to local heating, as well as awareness regarding occupational health and safety, were rather easy to improve within the workplace. However, implementing rules, instructions, and training was insufficient even after the project was completed. Hence, it was concluded that it was important to establish practice and knowledge on organisational levels, have adequate attitudes among managers, co-ordinate training, and determine ownership of responsibility to succeed with implementation.

Discussion

Our scoping review collected for the first time the available research findings concerning cold risk management practices for workplaces. From the 25 papers included in this review, two focus points were clearly outlined. Firstly, most previous literature focused on theoretical cold risk assessment where the authors emphasised that current practices were not adequate. Secondly, most papers in this review focused solely on low ambient temperature, without taking into consideration the effects of other parameters such as moisture and wind, which could limit the understanding of the full complexity of the risks.

Evaluation of Personal Protective Equipment

One of the prominent topics was thermal comfort, personal protective equipment, and clothing. We identified several knowledge gaps concerning worker protection and the lack of comfort as well as the prevention of health risks. Even though employees used the provided equipment, the insulation did not seem to be enough. The lack of insulation left workers either cold or in need of more layers, which in turn challenged their motor functions and dexterity. In the papers included in this review, the process of acclimatisation did not seem to be a determining factor. Rather, the consistency of current practices was insufficient, as observed in the study by Tirloni et al. (2018) which described gloves that still left workers' hands cold. Also, the study of Golbabaei et al. (2022) showed that available clothes did not provide sufficient protection against general whole-body cooling, putting workers at risk for cold injuries.

The IREQ model presented by Holmér (1984) was a commonly used tool in the included studies. However, as several papers concluded (Aptel 1988; Griefahn 2000; Griefahn & Forsthoff 1997), the model does not consider differences in sex or body constitution, nor the effects of wear and tear on clothing insulation properties (Alfano, Palella & Riccio 2013). The frequency of changing clothing ensembles or washing them was not adequately considered in any of the included papers. What also needs to be highlighted is the fact that the IREQ model has only been tested and validated on men. Therefore, an update of the IREQ model is warranted.

There appear to be knowledge gaps concerning the effect of biological sex. About half of the included papers stated the participants' sex, and a clear division between occupational sectors was seen. Most of the female representation occurred in indoor artificially cooled environments and male-dominated samples represented outdoor labour. Yet, none of the included papers raised this issue or discussed differences in management levels regarding protective measures. One potential concern is that PPE was not suitable and fitted to female workers. Questions also arose regarding whether research on individual differences has been delayed due to the long-term male domination in outdoor labour. The implementation of user-friendly PPE for workers also appeared to be insufficiently investigated. Only Naesgaard et al. (2017) evaluated user-centred design for cold protective clothing, but only for male workers. Due to the lack of actual practice in the workplaces and co-created solutions together with the users, knowledge gaps will exist in how cold-protective PPE is usable for specific work tasks, alone or together with other PPE. For example, cold protective clothing may interfere with PPE used for other workplace hazards, such as respiratory and hearing protection (Jussila et al. 2017).

This review also found a discrepancy between what "should be" and "what is." Even though policies and legislation were in place, the workers did not appear to follow them. Employees seemed not to be given enough support for maintaining thermal comfort. In this context, limited knowledge regarding protection and risk management may increase the risk of malpractices, which in turn can increase health risks and decrease efficiency (Mäkinen & Hassi 2002).

ISO Standards and Method Development

The papers regarding method development were technically oriented and hard to implement in the workplace. Even though several authors emphasised the importance of the evaluated tools, few were tested on occupational groups. The usability was only considered in two papers (Mäkinen & Hassi 2002; Risikko et al. 2003). Only the basic (first-level) cold risk identification was considered feasible, while the more advanced risk analyses required special expertise and instrumentation (Mäkinen & Hassi 2002). In addition, there is a need to further develop these methods, taking into consideration the changing climate, development of sustainable industries, and associated emerging occupational health risks.

Risk Treatment

In this review, barely a third of the papers focused on risk treatment and what comes after the risk assessment. Even though there were some recommendations on how cold risks could be mitigated, none considered interindividual differences. Neither did they mention the societal norms and gender dynamics within organisational levels, nor focus on other types of organisational issues such as scheduling or recovery time. Only two papers conducted in Portugal (Oliveira et al. 2014; Raimundo et al. 2015) collected data regarding the duration of breaks and found that almost half of all workers had no rest periods. Two papers (Indreiten, Albrechtsen & Cohen 2018; Risikko, Remes & Hassi 2008) brought up the importance of and difficulties in implementing interventions to decrease or handle cold exposure within an organisation. Risikko, Remes and Hassi (2008) stated that even though a good management method could be in place, for a new implementation process to be successful, management support, personnel participation, and acceptance are essential for changing already existing practices and cultures. Indreiten, Albrechtsen and Cohen (2018) added to this that flexibility, resilience, and adaptation are essential key concepts for the systematic management approach.

Other Considerations

Holmér (2001) stated that a good risk assessment tool has the purpose of systematically analysing and defining possible risks by assessing the type and dose of the exposure, which effects occur, how these and different types of exposures relate to each other and consider the individual variations. To assist employers, the International Organisation of Standardization (ISO) is constantly developing and renewing its output of standards. The (ISO 15743:2008), *Ergonomics of the thermal environment. Cold workplaces. Risk assessment and management* was developed to aid employers and OHS services in mitigating health risks among cold-exposed workers. However, this standard does not appear to have been updated in recent years and the ISO has not been able to provide any data on the actual usage of the standard. It thereby raises concern about to what extent the standard is used, what is needed for improvements, or if the right target groups have been pinpointed. The ISO 11079:2007 includes calculations on required clothing insulation, exposure duration and recovery time, which are all interesting to consider in cold workplaces. However, even though most standards can be used independently, to achieve a comprehensive workplace assessment, they should be used in conjunction with one another (Golbabaei et al. 2022). As Olesen (1995) emphasised, it is important to remember that these documents are not everlasting, as information and procedures may change, and international standards are frequently updated and validated. Also, new standards are developed. Even though updating and renewing are important, it also becomes difficult for users to keep track of the most recent revisions of instructions and guidance for their use. As Alfano, Palella and Riccio (2013) pointed out, the described models in different ISO standards also have several errors and inconsistencies leading to implementation problems.

What should also be emphasised is the fact that only the Nordic countries and Russia have participated in collaborative research over country borders. Risk management practices seem to differ widely between countries, leaving gaps regarding how general (global) standards and methods would perform in other cross-border contexts. Also noted is the lack of newly collected data in the included papers. In our literature search, the last stated year of data collection was 2013, making recent changes in practice hard to identify.

Methodological Considerations

This review started with thousands of references to screen, making systematic criteria and processes important. Grey literature was thereby excluded to focus on scientific papers. Hence, there is a risk that important perspectives for cold risk management were lost in this process. The search string, although comprehensive, might also have lacked certain terms that would have resulted in finding additional relevant literature, for instance regarding studies on wind effects, acclimatisation, and cold risk warning tools. A systematic procedure with the support of the software Covidence enabled blinded assessment by several reviewers, limiting any potential subjective biases in the selection process. Our literature search was limited to papers written in English and the Nordic languages and published after 1980. Therefore, there is a risk that important research conducted earlier or in other parts of the world might have been omitted. From the search string used in this review, dozens of review articles were identified and excluded (Fig. 1). It is striking that there were more review articles found than actual original research articles within the field. Finally, our scoping review included papers with a large variety of methodological approaches, hence, no assessment regarding risk of bias was performed. However, our general impression of the literature was that the study samples were in general small, biological sex was not considered, the studies did not involve prospective designs, and only presented crude measures of both exposure and outcome.

Implications for the Future

This review has identified several knowledge gaps in the field of cold risk management. One important aspect to emphasise is the co-creation and implementation of solutions within the organisations and among workers commonly exposed to cold conditions. Climate change will likely result in more severe weather events, such as heat waves, cold spells, and storms. In addition, the variability of weather will likely increase, challenging preparedness. This calls for more research about the adaptive capacity of organisations regarding workers' protection and health. In the future, cold exposure may also occur in combination with novel physical workplace exposures such as high-frequency vibration, nanomaterials, and heavy or rare metals. Therefore, research, method development and standardisation need to continue at a steady pace to maintain updated practices for both employers and specialists within occupational health and safety. Finally, there should be more focus on individual differences among workers regarding the efficacy of preventive measures, especially on female workers, as most previous research has been conducted on men.

Conclusion

The previous literature on risk management of cold work was mainly oriented around technical risk assessment. However, there seems to be a lack of knowledge regarding implementation, resulting in inadequate protection for workers. Moreover, research is scarce regarding sex-dependent differences in risk management among workers exposed to cold. These identified knowledge gaps warrant further high-quality investigations.

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CONFLICTS OF INTEREST

The authors declare that they have no conflicts of interest.

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SUPPLEMENTARY DATA 1.
LITERATURE SEARCH FOR THE SCOPING REVIEW

SEARCH STRING #1—COLD ENVIRONMENT
exp cold/ OR Cold temperature*.ti,ab,kw. OR Low temperature*.ti,ab,kw. OR Freezing .ti,ab,kw. OR Cold environment*.ti,ab,kw. OR Cold condition*.ti,ab,kw. OR exp extreme cold weather/ OR Extreme cold. ti,ab,kw. OR (Cold* adj3 Wet*).ti,ab,kw. OR (Cold* adj3 damp*).ti,ab,kw. OR (Cold* adj3 Rain*).ti,ab,kw. OR (Cold* adj3 Snow*).ti,ab,kw. OR exp cold climate/ OR Cold climate*.ti,ab,kw. OR Polar region*.ti,ab,kw. OR Antarctic*. ti,ab,kw. OR (Cold adj3 stress).ti,ab,kw. OR Sub-zero.ti,ab,kw. OR Below zero.ti,ab,kw. OR Cold work*.ti,ab,kw. OR Cold related.ti,ab,kw. OR Winter weather.ti,ab,kw. OR Cold weather.ti,ab,kw. OR (Work* adj3 Cold).ti,ab,kw. OR Cold exposure.ti,ab,kw. OR exp Arctic/ OR Arctic.ti,ab,kw. OR (low adj3 temperature*).ti,ab,kw. OR Wind chill.ti,ab,kw. OR Circumpolar.ti,ab,kw. OR Contact cooling.ti,ab,kw. OR Cold object*.ti,ab,kw.

and

SEARCH STRING #2—WORK-RELATED
exp occupation/ OR Industr*.ti,ab,kw. OR exp employment/ OR employment*.ti,ab,kw. OR exp occupational exposure/ OR (Work* adj3 environment*).ti,ab,kw. OR Occupational exposure*.ti,ab,kw. OR Work related.ti,ab,kw. OR Job related.ti,ab,kw. OR Employe*.ti,ab,kw. OR exp workplace/ OR Workplace*.ti,ab,kw. OR Work place*.ti,ab,kw. OR Occupational.ti,ab,kw. OR exp work/ OR job .ti,ab,kw. OR exp army/ OR military.ti,ab,kw. OR exp personnel/ OR labo?r.ti,ab,kw. OR Defence force.ti,ab,kw. OR air force.ti,ab,kw. OR conscript*.ti,ab,kw. OR navy.ti,ab,kw.

and

SEARCH STRING #3—RISK PLANNING
exp risk assessment/ OR Risk Assessment*.ti,ab,kw. OR Safety analys*.ti,ab,kw. OR risk adjustment*.ti,ab,kw. OR Risk Analys*.ti,ab,kw. OR Risk-Benefit Assessment*.ti,ab,kw. OR exp risk management/ OR Risk* Management*.ti,ab,kw. OR Risk Reporting*.ti,ab,kw. OR Risk Report*.ti,ab,kw. OR Incident* Report*.ti,ab,kw. OR Preventive measure*.ti,ab,kw. OR exp occupational safety/ OR occupational safety.ti,ab,kw. OR exp protective clothing/ OR Insulation clothing*.ti,ab,kw. OR exp health care planning/ OR Health Planning Guideline*.ti,ab,kw. OR (Guideline* adj3 Health Plan*).ti,ab,kw. OR Health Planning Recommendation*.ti,ab,kw. OR exp practice guideline/ OR guideline*.ti,ab,kw. OR ISO.ti,ab,kw. OR Occupational safety plan*.ti,ab,kw. OR Occupational health care plan*.ti,ab,kw. OR Primary prevent*.ti,ab,kw. OR Secondary prevent*.ti,ab,kw. OR exp accident prevention/ OR Injur* prevent*.ti,ab,kw. OR exp safety/ OR Code of practic*.ti,ab,kw. OR Threshold limit*.ti,ab,kw. OR Legislation*.ti,ab,kw. OR Intervention*.ti,ab,kw. OR Standard*.ti,ab,kw. OR guide*.ti,ab,kw. OR prevent*.ti,ab,kw.

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