ORIGINAL ARTICLE

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Evaluation of the efficacy of personal protective equipment against occupational exposure to cold

Avaliação da eficácia dos equipamentos de proteção individual para a exposição ocupacional ao frio

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ABSTRACT | Background: The temperature of climate controlled areas in the food industry varies from -35ºC to 12ºC to ensure the quality of food. However, this temperature range might be harmful to the health of workers. **Objective:** To analyze parameters related to occupational exposure to cold risks to calculate clothing insulation indices and establish the efficacy of personal protective equipment (PPE). **Methods:** In stage 1 we analyzed environmental variables (air temperature and velocity and relative humidity) and the metabolic rate; in stage 2 we calculated the resultant clothing insulation index; in stage 3 we calculated the basic clothing insulation required to maintain the thermal balance and investigated the efficacy of PPE. **Results:** While the air temperature was lower for activities developed in the freezing tunnel (secondary packaging department), required basic clothing insulation was higher for activities involving operating forklifts. **Conclusion:** Protection was efficacious for 83.3% of the analyzed activities, however, occurrence of thermal discomfort cannot be ruled out as a function of excessive clothing. Although protection was insufficient for 16.7% of the analyzed activities, breaks for thermal recovery neutralized the risk of hypothermia.

Keywords | cold temperature; heat transfer; personal protective equipment; food industry; occupational health

RESUMO | Introdução: Os setores climatizados, no ramo de indústrias alimentícias, apresentam variações de temperatura de -35 a 12ºC, as quais são necessárias para garantir a qualidade dos alimentos. Entretanto, essa faixa de temperatura pode ser um agente nocivo para a saúde dos trabalhadores. **Objetivo:** Estudar os parâmetros de exposição ocupacional ao risco frio para estimar o índice de isolamento térmico e determinar a eficácia dos equipamentos de proteção individual. **Métodos:** Na primeira etapa foram avaliadas as variáveis ambientais (temperatura do ar, velocidade do ar, umidade relativa do ar) e a taxa de metabolismo; na segunda etapa foi determinado o índice de isolamento térmico fornecido; e na terceira etapa foi calculado o índice de isolamento básico de vestuário exigido para manter o equilíbrio térmico e verificada a eficácia dos equipamentos de proteção individual. **Resultados:** Embora a temperatura do ar seja inferior nas atividades desenvolvidas no túnel de congelamento no setor de embalagem secundária, comparando com as atividades realizadas na câmara de estocagem de operar empilhadeira e transportar produtos, o índice de isolamento básico de vestuário exigido é maior nas atividades desenvolvidas com uso de empilhadeira, mesmo a temperatura sendo superior. Isso ocorre em função da velocidade do ar ser superior nas atividades realizadas nas empilhadeiras. **Conclusões:** Em 83,3% das atividades avaliadas a proteção se mostrou eficaz, porém, existe a possibilidade dos indivíduos sentirem desconforto térmico devido ao excesso de roupa fornecida. Apesar de a proteção ser insuficiente em 16,7%, as pausas de recuperação térmica eliminam o risco de hipotermia.

Palavras-chave | temperatura baixa; transferência de calor; equipamento de proteção individual; indústria de alimentos; saúde do trabalhador.

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INTRODUCTION

Brazil is one among the main meat exporting countries[1]. The poultry, beef and swine protein industry employs about 7 million people, which makes exposure to cold risks a public health concern, similar to contamination with agrochemicals and heat in the case of agricultural[3] and sugarcane[4] workers respectively.

Workers in several sectors, such as the food and port industries, are exposed to cold temperatures as a function of the need to preserve and maintain the quality of products[5] in compliance with the mandatory hygiene and sanitation regulations for perishable products. These workers are exposed to very high or very low temperatures which might seriously impair their health[6,7].

Exposure to cold is associated with several consequences for the health of workers, among which discomfort followed by pain in the involved body site stand out[8]. These symptoms might have physiological and psychological effects, including loss of concentration and of motor agility, eventually leading to the occurrence of accidents[10].

In the Brazilian legislation, occupational exposure to cold is only addressed in article 253 of the Consolidation of Labor Laws (Consolidação das Leis do Trabalho–CLT)[11], appendix 9 of Regulatory Standard (RS) 15 (insalubrious activities and operations)[12] and RS 29 (safety and health in ports)[13]. According to NR 36[13], which regulates work in the meat slaughter and processing industry, personal protective equipment (PPE) should be both comfortable and efficacious to avoid exposure to hazards, as per NR 06[15] and NR 09[16]. While the Brazilian laws categorizes clothing as PPE, it does not indicate the required fabrics or levels of protection as a function of the actual hazards to which workers are exposed.

These lack of standards for occupational exposure to cold in the Brazilian laws hinder the implementation of control actions by companies[17]. The Brazilian laws do not define standards to measure parameters such as air velocity, relative humidity, length of exposure or metabolic rate, nor does it indicate which PPE effectively neutralize the risks associated with exposure to cold.

Therefore, technical and objective regulations are needed to reduce the risks associated with occupational exposure to cold and the PPE able to neutralize such risks should be established to achieve effective protection and thus avoid the occurrence of diseases related to this occupational exposure, duly grounded on the international standards ISO 8996[18], ISO 9920[19] and ISO 11079[20].

As a function of the aforementioned considerations, the aims of the present study were to analyze parameters related to occupational exposure to cold, including length of exposure, relative humidity, air velocity and metabolic rate for workers exposed to temperatures -35ºC to 10ºC, calculate the resultant clothing insulation and determine the efficacy of the PPE used by workers exposed to these environmental conditions.

METHODS

CHARACTERIZATION OF THE STUDY SETTING

The present study was conducted at a poultry processing company in western Santa Catarina, Brazil, belonging to a major food company.

We analyzed 12 activities developed at two departments, to wit, seven activities carried out at the primary logistics department, which comprise: transporting products to the storage chamber (-24.6ºC to -29.5ºC), storage chamber cleaning (-24.5ºC to -29.6ºC), operating forklifts in the storage chamber (-24.5º to -29.5ºC), moving pallets and containers (0.0ºC to 6.0ºC), loading trucks (1.0ºC to 6.6ºC), cleaning the area (0.0ºC to 8.6ºC) and stretch film wrapping. The other five activities corresponded to the secondary packaging department and included: cleaning the semi-continuous freezing tunnel (-25.3ºC to -32.7ºC), cleaning the continuous freezing tunnel (-27.1–C to 35.3ºC), packaging (2.5ºC to 5.6ºC), palletizing (2.3ºC to 5.2ºC) and cleaning the area (2.1ºC to 5.3ºC). Fifty employees were allocated to these two departments and spent most of their working time exposed to temperatures below 10ºC — down to -35ºC in the cold storage chambers.

STUDY STAGES

To achieve the intended aims, the study was developed along three stages schematically depicted in Figure 1. In stage 1 we measured environmental variables and the metabolic rate, in stage 2 we calculated the resultant clothing insulation ($I_{cl,r}$); and in stage 3 we analyzed the participants' thermal balance conditions.

Stage 1: Measurement of environmental variables and metabolic rate

In this stage we measured the following environmental variables: room air temperature (ºC), relative humidity (%) and air velocity (m/s). We also calculated the participants' metabolic rate 60% during the working hours.

The criteria for devices selection were: resistance to humidity and temperature and precision level. All the

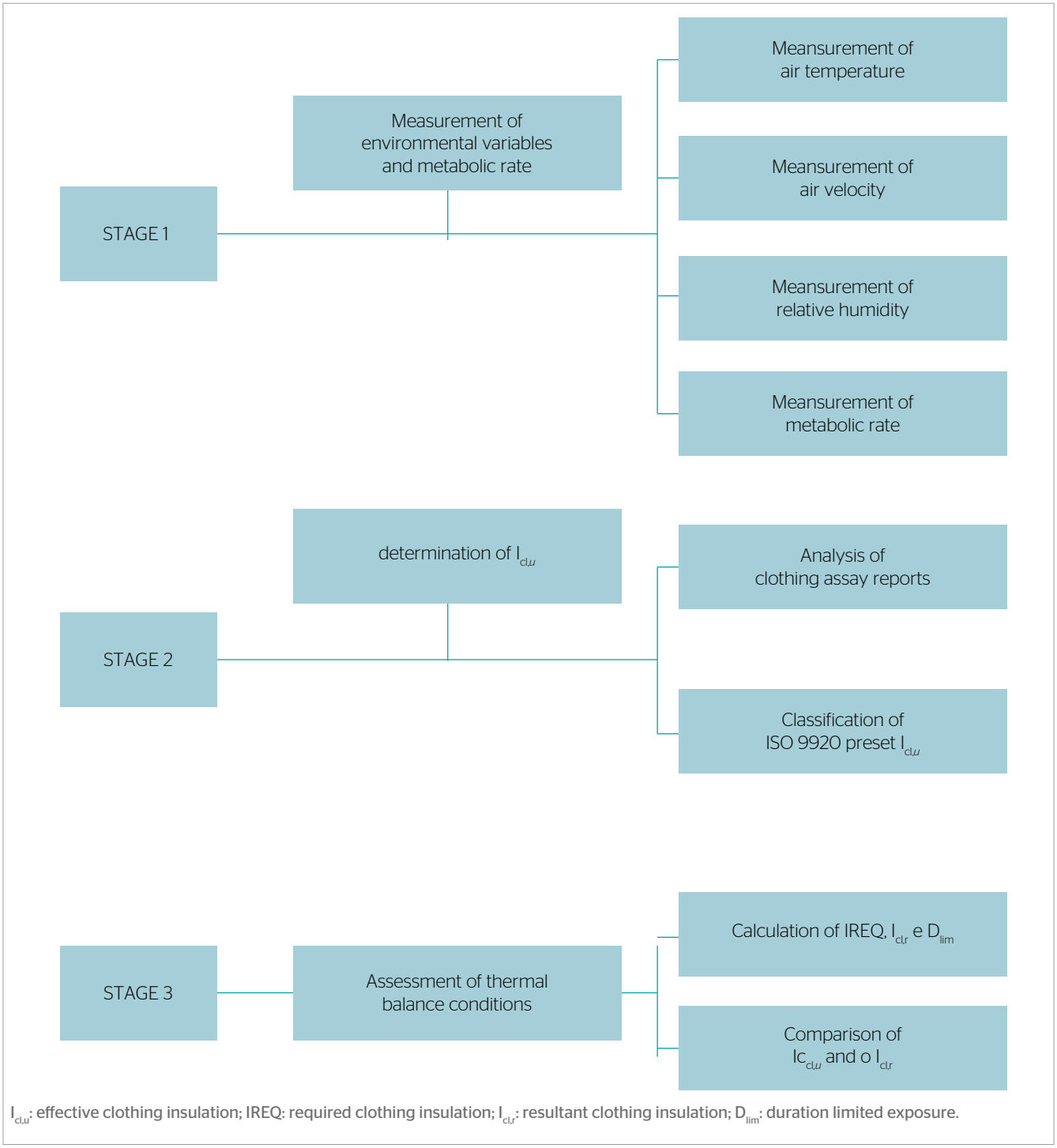

Figure 1. Simplified flowchart representing the study stages.

devices used for environmental evaluation were duly calibrated and had power sufficient to enable complete data collection.

Room air temperature

The air temperature at the site in where he analyzed activities were performed was measured with a portable Salvaterm 80j/K digital thermometer, with 0.10-ºC precision, placed 1.50 meter above the ground as recommended by the Brazilian Health Surveillance Agency[21]. Measurements were recorded every minute for 10 minutes.

Air velocity

Two criteria were applied to the air velocity measurement, being one for the following activities: transporting products to the storage chamber, moving pallets and containers and operating forklifts, all of which involved the use of motive power machinery. Ten records of machine speed were performed along 20 minutes.

The other criterion was adopted for the activities which did not involve motive power machinery. The air velocity in the course of these activities was instantaneously measured with a Pacer HTA 4200 digital thermo-hygro-anemometer, APT 100 air probe and velocity range 0.3 to 35 m/s, which was placed at about 1.5 meters above the ground for 30 minutes on the direction of the Cartesian x, y and z axes of all the analyzed sites, registering 10 records per axis. The mean velocity was obtained by adding the vectors of the three analyzed axes, x, y and z, using equation 1:

$$V = \sqrt{(V_x^2 + V_y^2 + V_z^2)} \quad (1)$$

For activities in which the thermos-hygro-anemometer did not detect any degree of forced air velocity, the air velocity was considered to be constant and equal to 0.4 m/s, which is the minimum described in ISO 11079, being due to the movement of human limbs[20].

Relative humidity

Relative humidity was measured with a digital Novus RHT-485-LCD thermos-hygrometer and transmitter with 0.0 to 100% range. Measurements were recorded every minute for 10 minutes.

Metabolic rate

The metabolic rate was calculated based on the participants' heart rate corrected for age and weight, according to ISO 8996 Appendix C Table C.1[18].

Heart rate was measured with two digital Geonaute and Reebok monitors placed on the participants' chest. Measurements were recorded during the performance of the same activity on different days of the week to a total of 30 participants, only one of whom was a woman. Measurements were instantaneously recorded every 2 minutes for 20 minutes to a total of 10 records per measurement. We also calculated the standard deviation to validate the data.

Stage 1 was approved by the research ethics committee of Unochapeco, ruling no. 1,923,000.

Stage 2: Determination of the effective clothing insulation ($I_{cl,u}$)

We first surveyed the PPE provided to the workers. We requested from suppliers the reports of the assays conducted by a laboratory accredited by the National Institute of Metrology, Quality and Technology (Instituto Nacional de Metrologia, Qualidade e Tecnologia–Inmetro) and the Ministry of Labor and Employment and presented at the time of applying for the due certificate of approval (CA). We also recorded the thermal resistannce (thermal insulation capacity) and mechanical resistance (to water penetration and tears) of PPE.

When the effective clothing insulation ($I_{cl,u}$) was not informed in the CA assay reports, ($I_{cl,u}$) was calculated by adding the insulation of each piece of clothing. The corresponding values are established in ISO 9920, having been obtained through measurements performed with thermal manikins in climatic chambers.

Stage 3: Assessment of the workers' thermal balance conditions

Once all the aforementioned measurements were performed, the mean values were entered in software IREQ 2008, version 4.2, described in ISO 11079 Appendix F, to calculate the minimum required basic clothing insulation which include estimates of the effects of air penetration into clothing and of the activity performed, thus resulting in a more accurate measurement of the effective clothing insulation.

The software allows calculating the minimal required clothing insulation ($IREQ_{min}$), neutral required clothing insulation ($IREQ_{neutral}$), $I_{cl,r}$ to achieve thermal balance, as well as the duration limited exposure (D_{lim}) when $I_{cl,u}$ is lower than $I_{cl,r}$.

Figure 2 depicts IREQ 2008 home screen, which includes boxes to enter the variables required to calculate $I_{cl,r}$.

IREQmin and IREQneutral represent actual insulation in static conditions without considering the effect of wind. Since both body movements and wind reduce the insulation of clothing as a function of the fabric permeability to the air and the activity performed, we chose to analyze $I_{cl,r}$ as calculated with software IREQ 2008, which consider the just mentioned aspects and thus provide more accurate measurements of the actual clothing insulation[22].

RESULTS

MEASUREMENT OF ENVIRONMENTAL VARIABLES AND METABOLIC RATE

Measurements were designated A, B, C, D, E and F as a function of the day when they were taken. The data were analyzed according to the particularities of each environmental variable.

We collected about 3,500 data points, which were used to calculate $I_{cl,r}$.

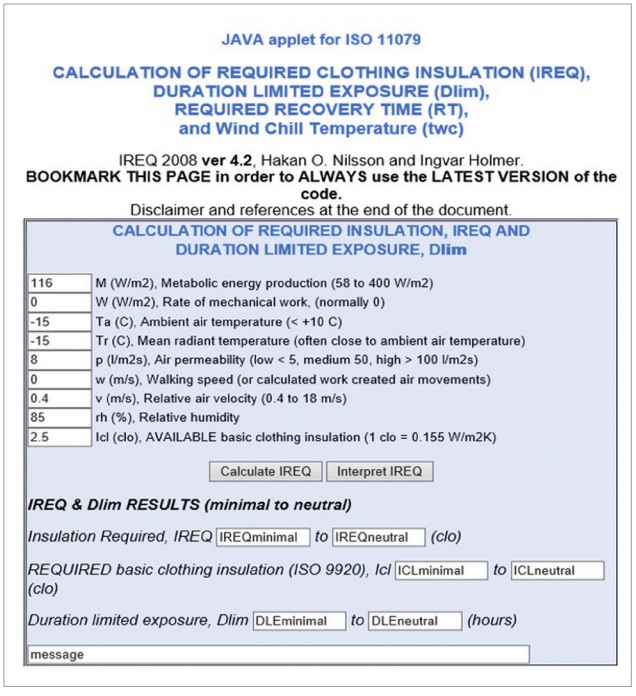

Figure 2. Home screen of the software used to calculate the required basic clothing insulation according to ISO 11079.

DETERMINATION OF THE EFFECTIVE CLOTHING INSULATION ($I_{CL,U}$)

During data collection we noticed that the employer provided a minimum of PPE against cold risks, which varied in quantity and type as a function of the activity performed by the employees and their level of thermal stress exclusively determined on the basis of the CA issued by the Ministry of Labor and Employment.

CA had been granted for all the available PPE, which was valid at the time of data collection.

Figure 3 lists the PPE used by the employees who performed the analyzed activities together with the effective clothing insulation ($I_{cl,u}$) of each piece of clothing.

Clo was not registered in the CA of any of the ten analyzed PPE components, two exhibited subjective indications of temperature level of working and only two had passed the water penetration test.

Figure 4 describes the ($I_{cl,u}$) of the set of clothing provided to the workers allocated to perform the analyzed activities in the primary logistics and secondary packaging departments. This index was calculated based on the reference values included in ISO 9920[19].

As Figure 4 shows, the highest ($I_{cl,u}$) corresponded to the activities performed in the areas with the lowest temperatures, i.e. the continuous and semi-continuous freezing tunnels and the storage chamber. These values were compared to $I_{cl,r.}$

ASSESSMENT OF THE WORKERS' THERMAL BALANCE CONDITIONS

Calculation of required basic clothing insulation

Table 1 describes $I_{cl,r}$ e $I_{cl,u}$ for the set of clothing provided to the workers allocated to the analyzed activities in the primary logistics and secondary packaging departments. These three indices were mutually compared to establish the degree of the protection afforded. When $I_{cl,u}$ is lower than $I_{cl,r}$, protection is insufficient, when $I_{cl,u}$ is higher than $I_{cl,r,}$ protection is excessive; in turn, protection is adequate when the value of $I_{cl,u}$ is intermediate to the interval of $I_{cl,r}$ presented by the software.

As Table 1 shows, protection was insufficient for transporting storage chamber products and operating forklifts in the primary logistics department. Therefore, continuous and prolonged exposure might be associated with risk of hypothermia for the allocated workers. Protection was excessive in the remainder

DESCRIÇÃO	I_{cl} (m²°C/W)	DESCRIÇÃO	I_{cl} (m²°C/W)
ROUPAS ÍNTIMAS			
Cuecas	0,03	Camiseta de manga curta	0,09
Roupa de baixo comprida	0,10	Camiseta de manga comprida	0,12
Camiseta de tirantes	0,04	Sutiãs e calcinhas	0,03
CAMISAS E BLUSAS			
Manga curta	0,15	Camisa de flanela, manga comprida	0,30
Manga curta leves	0,20	Blusa leve, mangas compridas	0,15
Normais, mangas compridas	0,25		
CALÇAS			
Curta	0,06	Normal	0,25
Leve	0,20	Flanela	0,28
VESTIDOS E SAIAS			
Saia leve (verão)	0,15	Vestido de inverno, mangas compridas	0,40
Saia grossa (inverno)	0,25	Macacão de trabalho	0,55
Vestido leve, mangas curtas	0,20		
AGASALHO LEVE E FECHADO			
Colete sem mangas	0,12	Agasalho médio	0,28
Agasalho leve	0,20	Agasalho grosso	0,35
JAQUETA			
Jaqueta leve de verão	0,25	Casaco de trabalho	0,30
Jaqueta normal	0,35		
FORRADA COM ELEVADO ISOLAMENTO			
Macacão de trabalho	0,90	Jaqueta	0,40
Calça	0,35	Colete	0,20
CASACOS			
Abrigo	0,60	Jaqueta impermeável	0,70
Jaqueta longa	0,55	Macacão forrado	0,55
DIVERSOS			
Meias	0,02	Sapato de sola fina	0,02
Meias, grossas. Curtas	0,05	Sapato de sola grossa	0,04
Meias, grossas, longas	0,10	Botas	0,10
Meia calça de nylon	0,03	Luvas	0,05

Figure 3. Personal protection equipment used by workers during the performance of the analyzed activities.

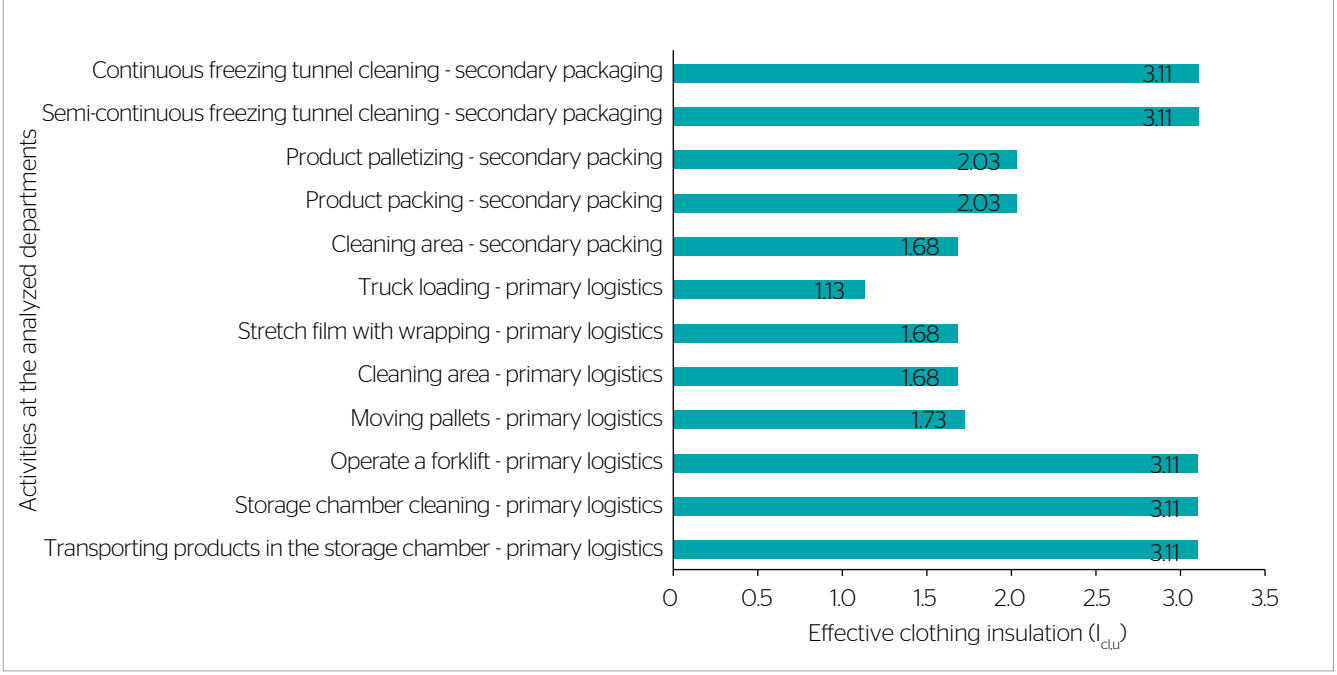

Figure 4. Effective clothing insulation ($I_{cl,u}$) the employees according to activity/department.

of the activities performed in the primary logistics departments, presented in average sets of $I_{cl,r}$ and $I_{cl,u}$ measurements.

The mean $I_{cl,r}$ was superior to $I_{cl,u}$ in all the measurements corresponding to the secondary packaging department, with consequent risk of overheating due to excessive clothing. However, the value of $I_{cl,u}$ for cleaning the semi-continuous freezing tunnel was merely 0.14 clo superior to that of $I_{cl,r}$ — hooded jackets and gloves — and thus close to the range of adequate protection.

On comparison of operating forklifts and transporting storage chamber products in the primary logistics department versus cleaning the continuous and semi-continuous freezing tunnels in the secondary packaging department, $I_{cl,r}$ was higher for the activities involving operating forklifts, even when the air temperature was higher compared to that of the freezing tunnels. The reason is that the air velocity is higher for the former, resulting in higher thermal exchange, with consequent reduction of the clothing insulation capacity.

DISCUSSION

The metabolic rate has inverse relationship with $I_{cl,r}$, i.e. the higher the former the lower the latter. Workers whose job demands lighter physical activity, of about 90 W/m², are exposed to higher risk of cold stress compared to workers who perform more vigorous physical activity, of about 120 W/m² [23].

Transporting products to the storage chamber and operating forklifts in the primary logistics department were performed in the storage chamber under similar conditions, the metabolic rate being 117 W/m² and 140 W/m², respectively. However, operating forklifts was associated with longer stay in the storage chamber — which might trigger a physiological response, since $I_{cl,u}$ is lower than $I_{cl,r}$ — and also longer exposure, which caused tremors and consequent increase of the heart rate, with the corresponding effect on the calculation of the metabolic rate.

The $I_{cl,u}$ for the activities involving transport of products in tunnels and chambers was 1.09 clo less than $I_{cl,r}$, which

Table 1. Interval of resultant clothing insulation presented by the software and effective clothing insulation of the sets of clothes provided to employees according to the activities performed at the two analyzed departments and degree of protection.

Department	Activity	*$I_{cl,r}$ (clo)	**$I_{cl,r}$ (clo)	$I_{cl,u}$ (clo)	Degree of protection
Primary logistics	Stretch film with wrapping	0,6	0,9	1,68	Excessive
Primary logistics	Area cleaning	0,4	0,8	1,68	Excessive
Primary logistics	Truck loading	-0,1	0,1	1,13	Excessive
Primary logistics	Operating forklifts	3,87	4,33	3,11	Insufficient
Primary logistics	Moving pallets and containers	0,8	1,2	1,73	Excessive
Primary logistics	Storage chamber cleaning	2,1	2,5	3,11	Excessive
Primary logistics	Transporting storage chamber products	3,8	4,2	3,11	Insufficient
Secondary packaging	Continuous freezing tunnel cleaning	2,1	2,5	3,11	Excessive
Secondary packaging	Area cleaning	0,3	0,6	1,68	Excessive
Secondary packaging	Product palletizing	1,1	1,4	2,03	Excessive
Secondary packaging	Product packaging	0,5	0,8	2,03	Excessive
Secondary packaging	Semi-continuous freezing tunnel cleaning	2,57	2,97	3,11	Excessive

*$I_{cl,r}$: value minimum of resultant clothing insulation presented by the software; **$I_{cl,r}$: value neutral of resultant clothing insulation presented by the software; $I_{cl,u}$: effective clothing insulation.

corresponds to two lab coats, and Dlim was 1h45min. $I_{cl,u}$ was 1.22 clo for operating forklifts, i.e. below $I_{cl,r}$, which corresponds to two anoraks, and Dlim was 1h40min. Therefore, there is a maximum limit to the time workers might spend in these activities, since the clothing provided by the employer is insufficient. However, these employees are not at risk of hypothermia, because they are granted 20-minute breaks for thermal recovery every 1h40min in compliance to the Dlim calculated based on ISO 11079[20].

For activity stretch film with wrapping, the variation of the air temperature was of up to 9ºC, which corresponds to a variation of $I_{cl,r}$ of 0.5 clo or a lab coat and thermal socks. This variation is due to the influence of the external air, which cannot be controlled due to the need to have openings in the docks to load the trucks. $I_{cl,r}$ might be calculated for the most critical situation and employees are free to decide on whether to remove or not a preset piece of clothing when the air temperature increases and causes thermal discomfort.

CONCLUSION

The present study might be useful for safety and health at work professionals as concerns quantitative assessments of whether the PPE used by workers effectively protects against cold risks. The reason is that the establishment of health hazard allowance to be paid in association with exposure to cold demands inspection of the workplace, including the adequacy of protection and potential exposure to cold risks harmful to health. However, NR 15 appendix 9[7] does not list the parameters to be analyzed in such evaluations.

Besides hazard pay, the present study contributes with technical grounds to the process and methods for assessing the efficacy of implemented protective measures, as established in NR 09 section 9.3.5.6[16].

As a function of the lack of parameters to assess exposure to cold in NR 15 appendix 9[5], medical legal decision making on hazard pay is exclusively based on the temperature of the air, which might lead to serious errors due to the lack of data on essential aspects, such as air velocity, relative humidity, metabolic rate and clothing insulation, which interfere with $I_{cl,r}$.

All the analyzed PPE had been issued CA for thermal agents, even though the Ministry of Labor and Employment does not require reporting clothing insulation indices. Manufacturers are free to choose whether to include or not this information in PPE assay reports, which hinders the accuracy of calculation given the need to use reference values.

Considering the methods applied in the present study, protection was efficacious for 83.3% of the analyzed activities. However, occurrence of thermal discomfort cannot be ruled out as a function of the excessive clothing provided to the workers. Protection was insufficient for 16.7% of the analyzed activities. Nevertheless, since the workers were granted 20-minutes breaks for thermal recovery every 1h40min and the maximum duration of exposure was 1h40min for operating forklifts and 1h54min for transporting storage chamber products, we conclude that although protection was insufficient, the breaks for thermal recovery neutralized the risk of hypothermia.

Given the scarcity of Brazilian studies on PPE against cold risks, we suggest performing quantitative assays of PPE with thermal manikins to define thermal insulation more precisely and thus eliminate the errors which might arise from the use of reference values, which do not consider the fabric type, thickness, warp and weft.

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