

# ASSESSMENT OF COLD STRESS FIELD MEASUREMENTS AND SUBJECTIVE ANALYSIS

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## INTRODUCTION

The occupational exposure to extreme thermal environments, either hot or cold, represents an issue that should be duly considered due to the very significant number of workers involved. In Portugal, probably because of its mild climate, this reality often neglected in the past is being overcome during the most recent years, as a result of the efforts of a few research teams that are giving a growing attention to these topics.

This work is dedicated to the study of cold thermal environments in Portuguese food distribution industrial units. The occupational cold exposure was first characterised by Oliveira et al (2008) in a large study that has quantified the typical thermal conditions of six activity sectors and where it is shown that the number of people working in the cold is much more important than it was initially predicted. From this representative survey, the food distribution sector is addressed in this paper due to its increasing importance in both economic and social terms.

In order to characterise the level of cold exposure a set of measurements were realized in 5 industries, corresponding to 26 workplaces. The method proposed by ISO 11079 (2007) based on the evaluation of the required clothing insulation to maintain the thermal balance of the body was adopted. To achieve a more complete knowledge in studies of human thermal environments, the assessment strategies should also consider methodologies focused on subjective analysis. Therefore, the characterisation of the population (gender, age, medical background, subjective judgements about the protective clothing and the thermal environment) and the work conditions (individual protection equipment, physical requirements of the activity, existence or not of rest periods, etc), are relevant issues that should be taken into account. Thus, as a complement to the field evaluations, a questionnaire consisting of 24 questions was developed and used for an extensive evaluation of the working conditions in cold environments.

## METHODS

The Required Clothing Insulation Index (IREQ), developed by Holmér (1984) and adopted by ISO as an International Standard (2007), was considered in this work to assess the level of thermal stress. This index is mainly supported by measurements of the physical parameters [air and mean radiant temperatures ( $t_a$  and  $t_r$ ), air velocity ( $v_a$ ) and humidity ( $rh$ )] and the estimation of individual parameters [metabolic rate ( $M$ ) and thermal insulation of clothing ( $I_{cl}$ )] and provides a method to evaluate the thermal stress in cold thermal environments. In addition, two

levels of physiological strain ( $IREQ_{neutral}$  and  $IREQ_{minimal}$ ) defined in terms of mean skin temperature, skin wettedness and change in body heat content are also considered. The clothing insulation required to maintain thermal equilibrium is calculated by satisfying the following equations, which are derived from the human heat balance equations:

$$IREQ = \frac{\bar{t}_{sk} - \bar{t}_{cl}}{M - W - E_{res} - C_{res} - E} \quad (1)$$

$$M - W - E_{res} - C_{res} - E = R + C \quad (2)$$

where  $\bar{t}_{sk}$  and  $\bar{t}_{cl}$  are the mean skin temperature and the mean clothing surface temperature [ $^{\circ}\text{C}$ ],  $M$  is the metabolic rate [ $\text{Wm}^{-2}$ ],  $W$  is the effective mechanical work [ $\text{Wm}^{-2}$ ],  $E_{res}$ ,  $C_{res}$ ,  $E$ ,  $R$  and  $C$  are the heat exchanges by respiratory evaporation and convection, by evaporation, radiation and convection at the human body surface [ $\text{Wm}^{-2}$ ], respectively.

The experiments were realised in 5 food distribution units. The measurements of the physical and individual parameters needed to calculate the IREQ index took place from January to March and a total of 26 workplaces were evaluated, namely 6 freezing chambers, 8 refrigeration chambers and 12 free-floating or controlled air temperature manufacturing workplaces.

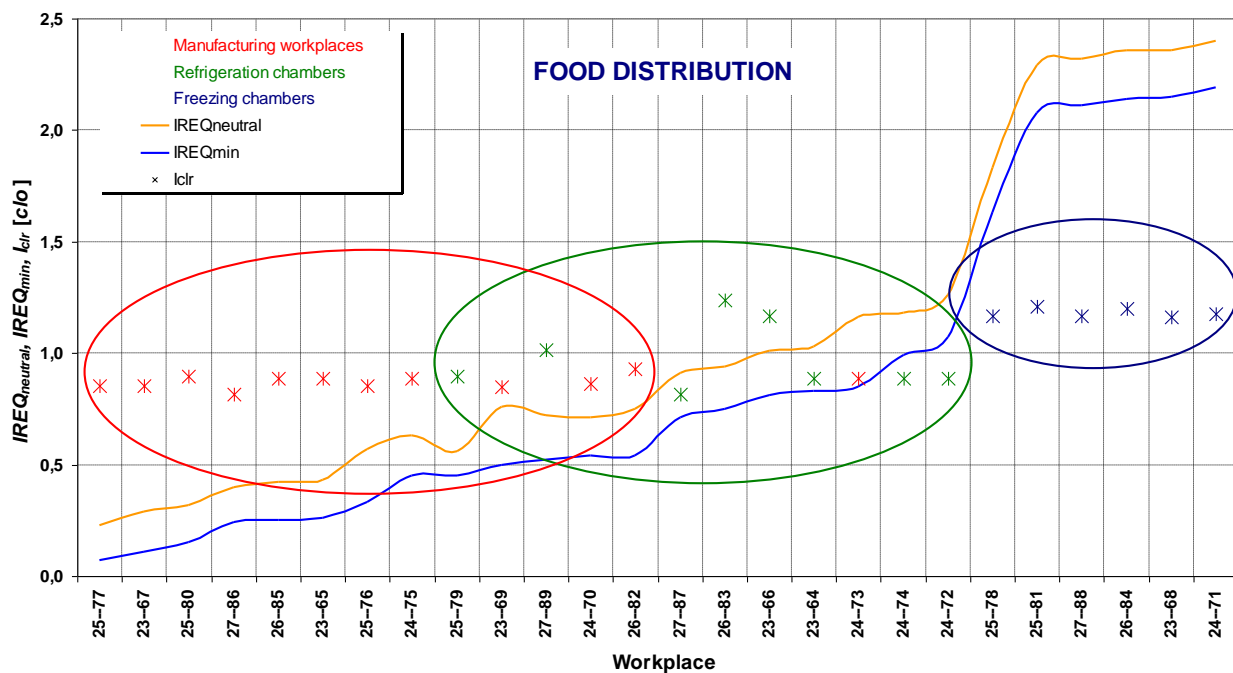
From a complementary perspective, the aim of the subjective survey is to provide a global picture of the actual working conditions in Portugal. Therefore, the questionnaire was distributed in food industrial units - large and medium size supermarkets -, across 17 out of 18 provinces of Portugal. The collected sample comes from 61 units and a total of 1575 workers valid responses. Due to the sample size and the large amount of data, the questionnaires were submitted to an electronic optical reading.

The questionnaire is divided in two parts. The first one consists in a very simple characterisation of the worker through 3 questions where the gender, the age and the clinical history are assessed. This last issue is based on ISO 12894 (2001) which lists the health effects, both physiological changes and disorders that may arise whenever cold or hot exposures are considered. The second part is divided in two sections, which have a total of 24 questions. The first section consists of multiple choice questions, while the second is based on a 10-degree judgement scale. This 10-degree scale comprises 2 central points and two times 4 degrees increasing intensity. In this second part, beyond the identification of some parameters related to the workplace, a more detailed assessment of the personal protective clothing and of the thermal environment is foreseen. For the latter, ISO 10551 (1995) was taken into account. The statistical analysis was done with the Statistical Package for the Social Sciences (SPSS) software.

## RESULTS

The relationships between the resultant clothing insulation,  $I_{clr}$ , and the required clothing insulation,  $IREQ$ , for both neutral and minimal criteria are shown in Figure 1 for all workplaces under analysis. If the selected clothing ensemble provides adequate insulation, then  $IREQ_{minimal} \leq I_{clr} \leq IREQ_{neutral}$  and the points that characterize this condition are located between the  $IREQ_{minimal}$  and  $IREQ_{neutral}$  lines. On the other hand, if the available clothing ensemble ( $I_{clr}$ ) provides more or less insulation than required, then the points that characterize these conditions are located above the  $IREQ_{neutral}$  line or below the  $IREQ_{minimal}$  line, respectively.

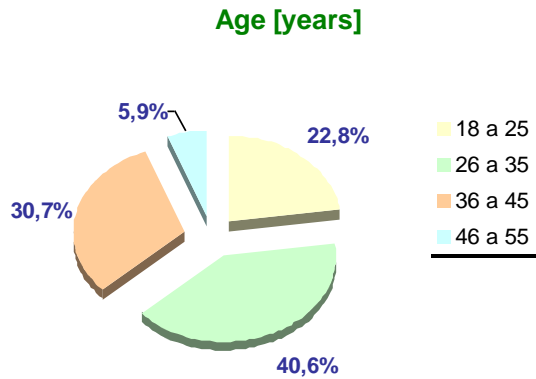
Ordering the values of  $IREQ_{minimal}$  increasingly, it is possible to group the characteristic workplaces mentioned before. Accordingly, the encircled zone on the left refers to manufacturing workplaces, the refrigerating chambers are typically positioned in the centre and the freezing chambers are placed to the right. It must be underlined that the encircled zones are only representative since different types of workplaces can indeed be located within each particular zone. The freezing chambers represent the most severe case since in all of these workplaces the protection provided by the available clothing ensemble is insufficient ( $I_{clr} < IREQ_{minimal}$ ). The manufacturing workplaces show an opposite situation since the selected clothing ensemble widely provides too much insulation ( $I_{clr} > IREQ_{neutral}$ ). The refrigerating chambers show results in the three possible situations. From a global point of view it can be stated that the recommended pattern, represented by results in the clothing regulatory zone ( $IREQ_{minimal} \leq I_{clr} \leq IREQ_{neutral}$ ), corresponds to only 12% of the workplaces.



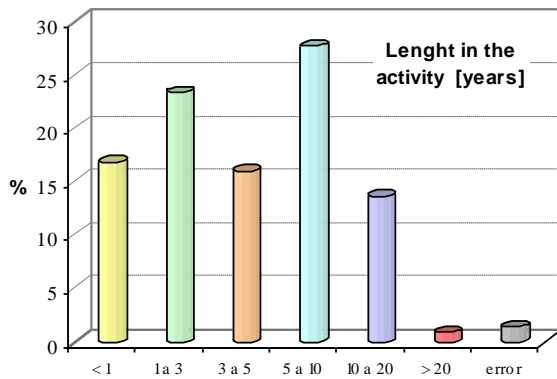
**Figure 1** Values of the required clothing insulation ( $IREQ_{neutral}$ ,  $IREQ_{minimal}$ ) and resultant clothing insulation ( $I_{clr}$ ).

The results of the statistical analysis of 1575 questionnaires obtained all over Portugal main land are presented and discussed next. The discussion of the entire questionnaire is not possible in this paper due to size limitations and can be found elsewhere (Oliveira, 2006). Therefore, a group of 8 questions considered representative of the different parts and sections of the questionnaire was selected for analysis.

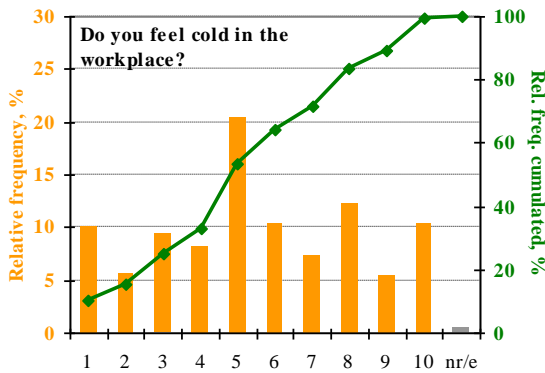
Figure 2 shows that there are no workers with more than 55 years old. In addition, 93,7% of the workers have less than 45 years old and 63,1% less than 35. This activity sector is thus characterised by a young population. The distribution of the workforce by gender (*vd.* Figure 3) shows that the majority of workers are women (78,1%). The length in the activity is classified into 6 different categories. Figure 4 shows that 56,3% of the workers remain in the same occupation for less than 5 years and 84,1% for less than 10 years. The highest percentage corresponds to the 5 to 10 years class and the lowest fit in the class of more than 20 years in the same type of activity.



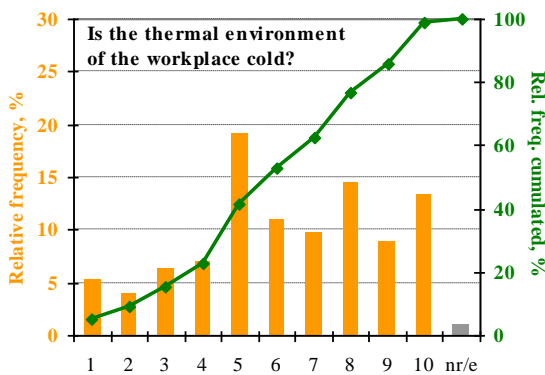
**Figure 2** Age



**Figure 4** Lenght in the activity [years].

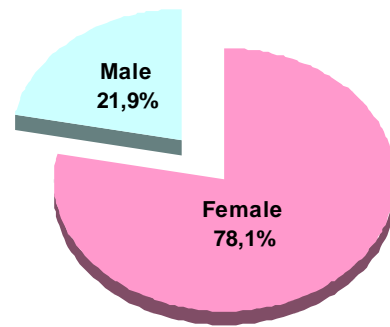


**Figure 6** Do you feel cold in the workplace?

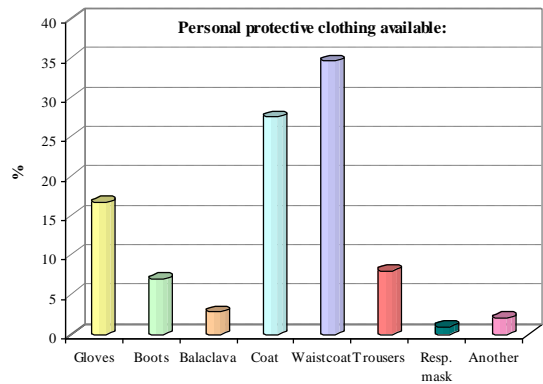


**Figure 8** Is the thermal environment of the workplace cold?

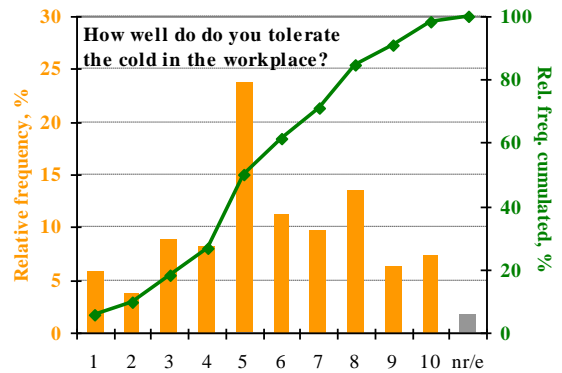
### Gender



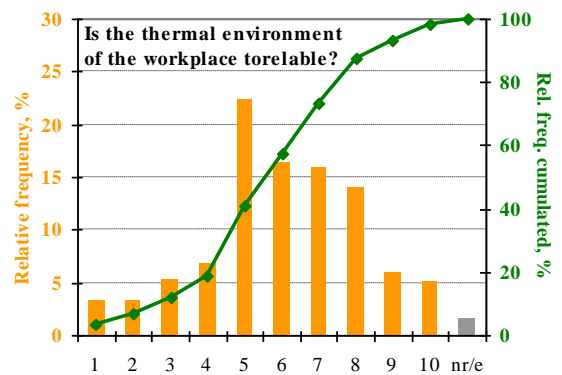
**Figure 3** Gender



**Figure 5** Personal protective clothing available.



**Figure 7** How well do you tolerate the cold in the workplace?



**Figure 9** Is the thermal environment of the workplace tolerable?

Figure 5 identifies the protective clothing available and shows that the majority of the respondents states that the waistcoat (59,6%) and the coat (47,3%) are the most common protective garments, followed by the gloves (28,8%).

Figures 6 to 9 are directed to the characterization of the personal thermal state and to the assessment of the thermal environment, namely in terms of the thermal perception and personal tolerance. Figure 6 shows that the results of the individual judgements in terms of the feeling of cold are distributed across the scale. In this case 53,7% of the votes are in the 1 to 5 range and 45,8% between 6 and 10. The highest percentage corresponds to level 5 with 20,4%. On the other hand, Figure 7 shows that the results are equally distributed (50,2% and 49,8% respectively in the 1 to 5 and 6 to 10 ranges) but the middle levels have the highest percentages which indicates that the workers are acclimatised to the cold. Once again, level 5 presents the highest percentage of the votes with 23,6%. Figure 8 assesses the thermal perception of the work environment. It shows 41,7% of the results in the range 1 to 5 and 57,4% in the 6 to 10 range.

Figures 6 and 8 highlight a behaviour that was put in evidence during the field evaluations. In fact, the sensation of cold was reported, however the workers have the perception that the thermal environment is even colder. Figure 9 refers to the personal tolerance and shows that the majority of the votes (57,4%) are located in the 6 to 10 range, suggesting that this workers tolerate quite well the thermal environment of the workplace but there is still a significant minority (42,6%) who doesn't.

## CONCLUSIONS

The present results demonstrate that a significant percentage of the workers are repeatedly exposed to extreme conditions and that the clothing ensembles worn by the workers are inadequate. Actually, only about 12% of the workplaces have an estimated  $I_{clr}$  value in the area between the  $IREQ_{minimal}$  and the  $IREQ_{neutral}$ , where the selected clothing ensemble provides sufficient insulation. Therefore, a careful selection of the clothing is recommended in order to adapt it according to the activity and to the work environment.

The discussion of the questionnaire presented in this paper is restricted to a few questions. The analysis is thus limited, but it clearly shows that the subjective assessments can play an important role as a complement to field measurements. In fact, the information that can be made available through individual inquiries to the workers can indeed be of great significance and may enable relevant statistical analysis. However, it should be noted that this kind of questionnaires describes the working conditions as perceived by the respondents.

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