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Evaluation of Occupational Cold Environments: Field Measurements and Subjective Analysis

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Abstract

The present work is dedicated to the study of occupational cold environments in food distribution industrial units. Field measurements and a subjective assessment based on an individual questionnaire were considered. The survey was carried out in 5 Portuguese companies. The field measurements includes 26 workplaces, while a sample of 160 responses was considered for the subjective assessment. In order to characterize the level of cold exposure, the Required Clothing Insulation Index (*IREQ*) was adopted. The *IREQ* index highlights that in the majority of the workplaces the clothing ensembles worn are inadequate, namely in the freezing chambers where the protection provided by clothing is always insufficient. The questionnaires results show that the food distribution sector is characterized by a female population (70.6%), by a young work force (60.7% are less than 35 years old) and by a population with a medium-length professional career (80.1% in this occupation for less than 10 years). The incidence of health effects which is higher among women, the distribution of protective clothing (50.0% of the workers indicate one garment) and the significant percentage of workers (> 75%) that has more difficulties in performing the activity during the winter represent other important results of the present study.

Keywords

Cold stress; field survey; risk assessment; subjective assessment

1. Introduction

The occupational exposure assessment to environmental conditions represents an issue that should be duly considered in many different activities. As a consequence, the improvement of Occupational Safety and Health (OSH) keeps motivating several research teams to carry out scientific studies, namely through risk assessment analysis in the field. Many research studies could be cited to highlight this concern and focus on OSH, namely in noise[1,2], vibration[3], light[4] and electromagnetic fields exposures[5].

In the case of the thermal environment, the exposure to moderate and extreme thermal environments, either hot or cold, achieved an increasing interest in the scientific community in the recent years and this field is now an emergent area of investigation. In fact, thermal comfort[6,7] and heat stress[8,9] assessments are being looked at with a renewable motivation, now followed by a more recent concern on cold stress studies[10,11,12,13,14,15].

Based on a field survey carried out in Portugal, this work is dedicated to the study of cold thermal environments. The occupational cold exposure, assessed in terms of the Required Clothing Insulation Index (*IREQ*), was first characterised by[16] in a study that has quantified the typical thermal conditions of six activity sectors, namely in fish, meat, milk-food production, conservation and distribution industrial units. This study shows that the number of people working in cold environments is much more important than initially predicted.

In the above-mentioned study, the aim was restricted to the use of the *IREQ* index proposed by[17] as a tool for the design of working practices in cold environments. The role of *IREQ* index for this purpose has been a focus of discussion since its publication[18] where the work developed by[19] represents a good example soon after ISO Technical Report on the *IREQ* index[17]. Meanwhile, ISO has changed the status and the Technical Report is now an International Standard. Thus, it was considered that the previous study should be reanalysed according to the new *IREQ* index as defined in[20].

On the other hand, it is widely recognized that the activities developed in both moderate and extreme thermal environments should be evaluated from multiple perspectives and subjective assessments are being looked at with increasing interest[21, 22, 23]. These two facts apply to a new and more detailed approach - combining a field evaluation with a questionnaire survey - that resulted in the present study now focused in the food distribution sector.

In many countries this activity sector is growing at a constant rate and therefore a detailed occupational study in such industrial plants led to the main motivation for the present research which can be of potential interest and regarded as a valid contribution to different countries and industrial activities. The Portuguese food distribution activity sector has assumed an increasing social and economic relevance that duly justifies an extensive research in order to characterize the actual working conditions. According to the Annual Book of the Portuguese Food Distribution Association of 2004, more than 39,000 workers and about 1,800 large and medium size supermarkets were registered[24)]. More recently, the Portuguese Association of Distribution Industrial Units (APED) states that the number of workers increased to more than 48,000 in 2007 and more than 55,000 in 2008 during which 157 new industrial units were created[25)].

The present work is thus aimed to characterize the working conditions in the food distribution sector by means of field measurements, cold exposure evaluations and subjective assessments with a questionnaire. This objective is clearly identified with the very recent ISO standard[26)] focused on environmental surveys involving physical measurements and subjective responses of people. Several measurements were carried out in 5 Portuguese representative industries. These consisted of large and medium size supermarkets, owned by an important economic group, which has been formally invited to participate in this study and has immediately accepted and encouraged the project that ended in 2011. This active cooperation included an extensive subjective assessment through the participation of all the workers of the 5 industrial units.

2. Materials and Methods

2.1 IREQ model

The evaluation of the thermal stress is mainly supported by measurements of the physical parameters [air temperature (T_a), mean radiant temperature ($\overline{T}_r$), usually estimated from the globe temperature (T_g), air velocity (v_a) and humidity (rh)] and the estimation of individual parameters [metabolic rate (M) and thermal insulation of clothing (I_{cl})], which are assessed in terms of the Required Clothing Insulation Index, *IREQ*. Developed by[18)] and adopted by ISO as a Technical Report in 1993[17)], and as an International Standard in 2007[20)], the *IREQ* index provides a method to characterize cold stress. With the support of the human heat balance equation, the *IREQ* index represents the clothing insulation required to maintain thermal equilibrium[17, 20)].

The physiological strain is proposed at two levels, neutral and minimal, in terms of mean skin temperature, skin wettedness and change in body heat content, which represent no or minimal cooling and the highest admissible body cooling during work, respectively.

When the resultant clothing insulation of the selected ensemble, I_{clr}, calculated on the basis of the intrinsic clothing insulation (I_{cl}) to account for the effect of body motion, posture and wind, is less than the calculated required clothing insulation (*IREQ*), exposure has to be time-limited to prevent progressive body cooling. Thus, a duration limited exposure (*DLE*) is defined, for both levels of strain, in terms of the recommended maximum time of exposure with available or selected clothing[17, 20)].

2.2 Industrial units and workplaces

The field evaluations were performed in 5 industrial units and the measurements took place from January to March. A total of 26 workplaces were considered, embracing freezing (6) and refrigerating (8) chambers and free-floating or controlled air temperature manufacturing workplaces (12). The industrial units where the field evaluations took place employed 1547 workers. However, only 350 of these individuals were consistently exposed to cold thermal environments. Therefore, for the subjective assessment of the present survey, only those 350 workers could be considered, but the authors were authorized to distribute only 260 questionnaires. From these 160 valid questionnaires were obtained and a response rate higher than 50% was obtained in 4 out of 5 units. The highest and lowest values were 78 and 30%, respectively.

2.3 Physical and individual parameters

The measurement of the physical parameters was carried out according to[27)]. The field evaluations were performed with a mobile and portable apparatus that incorporates three arrays of sensors, placed at 0.1 m, 1.1 m and 1.7 m above the floor. These levels correspond to the ankles, abdomen and head heights for a standing worker.

Equipment from Testo was used for the measurements, namely the data-loggers 175-T2 (ref[a] 0563 1755) for T_a and T_g temperatures and the 445 (ref[a] 0560 4450) for v_a and *rh* recording. The globe temperature

was measured by a globe of 50 mm diameter made of a 0.3 mm cooper plate, in the center of which an air temperature sensor from Testo (refª 0613 1711) was placed. The mean radiant temperature was then estimated using the globe temperature according to ISO 7726 specifications. The v_a and *rh* sensors were Testo (refª 0635 1049), (0 to 10 m/s; -20 to +70 ºC) and Testo (refª 0636 9741), (0 to 100% *rh*; -20 to +70ºC), respectively. With this system programmed to record each parameter the air and globe temperatures were measured at the 3 levels while the air velocity and humidity were measured only at the abdomen level. After an appropriate stabilization period the physical parameters were recorded simultaneously with a one minute time step and evaluated during an one-hour. The mean values obtained during the recording period were then used for the *IREQ* determination, leading therefore to an average estimation of the cold stress.

The activity level (*M*) was estimated according to[28)], using the methods of level II of accuracy. Whenever we got permission from the workers the metabolic rate was also estimated on the basis of heart rate measurements using a chest electrode belt with a telemetric heart rate transmitter (Sigma Sport PC 1600) placed on the subject. Four measurements were performed and the results of these estimations have shown a good agreement with the standard procedure.

The intrinsic thermal insulation of the ensemble (I_{cl}) was calculated following[29)] and[30)] by adding the values corresponding to each garment. For this purpose, a questionnaire with a set of figures representing different types of garments was used and the workers were asked to identify the garments worn. In order to assess the inaccuracies in the estimation of I_{cl} a complementary study was performed. The protective garments used by the workers were kindly borrowed by the economic group that participated in the survey, and measurements of the thermal insulation were performed in a climate chamber with a thermal manikin according to[30)].

2.4 Questionnaire

In order to provide a more complete description of the working conditions, a questionnaire was distributed to the workers of the food distribution units that participated in the present study. In fact, the information made available through individual inquiries can be of great significance and may enable relevant statistical analysis. It should be noted that the present questionnaire describe the working conditions as perceived by

the respondents and that in this work there was not any direct contact between the workers that participated in the survey and the researchers who promoted it.

The questionnaire is divided in two parts. The first one consists of a brief characterisation of the worker through 3 questions in which the gender, the age and the clinical history are considered. This last issue is based on[31] 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 has a total of 24 questions. The first section consists of multiple choice questions, while the second is based on a 10-level judgement scale. In this second part, beyond the identification of some parameters related to the workplace, more detailed assessments of the personal protective clothing and of the thermal environment are foreseen. For the latter[32] was taken into account.

To complete the questionnaire a period of 15 minutes is estimated. Table 1 presents the list of all the questions of the questionnaire. The statistical analysis was done with the Statistical Package for the Social Sciences (SPSS) software. Descriptive statistical methods were used for all the questions of the questionnaire. In addition, for the questions considered more interesting *t-student*, Spearman's Rho and Principal Component Analysis tests were used.

3. Results

Physical and Individual Parameters

The values of T_a, T_g, v_a and rh are shown in Table 2. The freezing chambers can be generally characterized in terms of a temperature range between -10 and -20 ºC, the refrigerating stores from 0 to 10ºC and the manufacturing workplaces between 10 and 15ºC. The manufacturing workplaces have generally lower rh values than the cold chambers, which are characterized by mean values higher than 90%. Usually, the mean air velocities are lower than 1 m/s, but in the cold chambers the intermittent operation of the cooling units leads to important fluctuations.

The values of the available clothing insulation (I_{cl}) ranged between 1.02 and 1.55 *clo*. Table 1 shows that the mean values of I_{cl} were equal to 1.09 for the manufacturing and 1.22 *clo* for the refrigerating cold chambers. In the most severe workplaces, *i.e.*, in the freezing chambers, the mean value of the available clothing insulation was 1.48 *clo*. The results of the complementary assessment of the thermal insulation of

8 cold protective clothes used by the workers show that the mean value of the measured thermal insulation was 0.35 *clo* above the estimated. The thermal insulation of 21 typical indoor garments was also measured and the results show that the estimated values were usually slightly overestimated[33, 34]. The mean values of the metabolic rates were equal to 153.1 $W.m^{-2}$ in the manufacturing workplaces, 160.9 $W.m^{-2}$ for the refrigerating chambers and 151.0 $W.m^{-2}$ for the freezing chambers.

IREQ index

The relationships between the resultant clothing insulation, I_{clr}, and the required insulation, *IREQ*, for both neutral and minimal levels of strain obtained with[17] and[20] are shown in Fig. 1, in which the reference to the workplaces is presented as a code where the letters FD are assigned to the Food Distribution sector and the following two digits are consigned to the industrial unit and the workplace, both sequentially numbered. In the case of[17] all the workplaces (26) were analyzed, but for[20] due to its restrictions ($T_a \leq 10$ ºC; 0.4 $m.s^{-1} \leq v_a \leq 18$ $m.s^{-1}$; $I_{cl} > 0.078$ $m^2.K.W^{-1}$ (0.5 *clo*)) only 15 workplaces were considered. In order to account for the reduction of insulation due to body movements the I_{clr} values shown in Fig. 1 were calculated according to[17], *i.e.*, by reducing I_{cl} values 20 and 10%, respectively for activities where M is higher or lower than 100 $W.m^{-2}$. 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 $IREQ_{neutral}$ values. 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 $IREQ_{neutral}$ or below the $IREQ_{minimal}$ values, respectively.

Ordering the values of $IREQ_{minimal}$ increasingly, it is possible to group the 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 is important to point out 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.

The detailed results obtained with[20] are summarized in Table 3. The required insulation values varied from 0.4 and 2.3 and from 0.7 and 2.7 *clo* for the minimal and neutral levels of strain, respectively. The *IREQ* ranged between 0.4 and 2.1 *clo* for the minimal level and from 0.6 and 2.4 *clo* for the neutral condition, while the corresponding *DLE* variation was between 0.7 and 2.6 hours and from 0.5 and 2.7 hours.

The relationships between *DLE* and *IREQ* for the cases with insufficient clothing insulation ($I_{clr} < IREQ_{minimal\ or\ neutral}$) are represented in Fig. 2 for both levels of strain and take only into account the results obtained with[20]. The higher values of *IREQ* are seen to correspond to the lower *DLE* values. Hence, the refrigerating chambers show a trend to present higher *DLE* values and lower *IREQ* values, while the freezing stores are characterized by a higher level of strain, thus lower *DLE* values and more requirements in terms of clothing insulation.

Subjective Assessment

A complete descriptive statistical analysis of the 160 questionnaires is presented next. This presentation is not sequential, *i.e.*, there are questions in different parts and sections of the questionnaire that are related and are thus analysed together. Therefore, 4 groups of questions are considered (general aspects, health effects, thermal environment and personal protective clothing).

General Aspects

In the industrial units considered 95.7% of the workers are less than 45 years old and 60.7% less than 35. The distribution of the workforce by gender shows that the majority of workers are women (70.6%). The length in the activity is classified into 6 different categories and 40.7% of the workers have remained in the same occupation for less than 5 years and 80.1% for less than 10 years. The highest percentage corresponds to the 5 to 10 years class (39.4%) and the lowest fits in the class of less than 1 year in the same type of activity (6.3%).

The distribution of the labour force by workplace shows that part of the workers have multiple activities and are not restricted to one particular workplace and the results show that 24.4% of the respondents point out more than one alternative. Hence, the relative frequencies correspond to the ratio between the number of votes in a particular workplace and the total number of votes (220). The results indicate that the Cold

Chambers (18.1%), the Delicatessen (17.7%) and the Fish Market (16.4%) are the workplaces with the highest percentage of answers.

The analysis of the rest periods demonstrates that 49.4% of the workers do not have any rest period in the work routine and 42.5% have 1 or 2 breaks. For respondents that point out the existence of rest periods, 53.4% estimate that the duration of the rest period is less than 15 minutes and 34.2% between 15 and 30 minutes.

The results for the permanency in the coldest workplace, typically the cold chambers, show that the majority of the workers (31.9%) state that the period spent in the coldest place is less than one hour and for 28.1% the duration ranged between 1 and 3 hours. This is highlighted in Fig. 2 with solid lines for *DLE* values of 1 and 3 hours.

Fig. 3 (Q-2.15) shows that the results about the appearance of sweating are spread along the 10-level judgment scale (level 1 - do not often sweat; level 10 - often sweat) but with a percentage higher than 50% in the 6 to 10 range. If the results of the physical demand of the activity, with a mean value of 7.67 and 91.9% of the answers refer to levels equal or higher than 5 (*vd*. Fig. 3 (Q-2.16)), are added to this analysis, since the appearance of sweating in cold environments is related to the physical demands of the activity and to the selection of the adequate clothing insulation, it becomes clear that the selection of the clothing does not considers the temperature level and the metabolic rate. It is also important to point out that women classify the physical activity as more demanding ($p < 0.05$) and a value of 0.341 for the Spearman's rho coefficient ($p < 0.01$) was obtained between Q-2.15 and Q-2.16.

The assessment of repetitive occupations in cold thermal environments is a matter of concern, since repetitive and monotonous tasks have a psychological impact and are often among the major causes of accidents. Fig. 3 (Q-2.17) shows that the range between 6 and 10 was selected by 77.5% of the workers, and among the 21.3% that voted in the 1 to 5 range, 13.1% correspond to level 5.

Health Effects

The characterization of the health effects arising in cold conditions is an issue that deserves special attention. The objective is to identify and highlight this issue in order to support preventive measures

which, in this case, are particularly important. The health effects specified in the questionnaire are the ones referred in ISO 12894 (2001)[31].

The majority of the respondents (62.5%) do not answer, which indicate that none of the mentioned health effects represent a problem for the worker. However, 35.6% point out one kind of health effect and 4.4% mark at least two. The analysis of the absolute frequencies show that the other health effects (33) and the respiratory (20) are the most referred to. By crossing the results of the health effects with the gender and type of workplace, the results show that the incidence of health effects is higher among women ($p<0.05$). In the case of cardiovascular and metabolic problems all the answers correspond to women, while for respiratory and other health effects, the majority of answers correspond to women (76.5 and 79.3%, respectively). Moreover, the Cold Chambers (5.9%) and the Fish Market (5.5%) are the workplaces with the majority of occurrences. This is in agreement with the study of[43] where the odds ratio from the upper limbs was significantly higher for females compared to men in the fish industry.

Thermal Environment

The thermal environment is the most relevant topic in the questionnaire and is assessed by several questions. In the question about the most difficult period of the year to perform the activity, 75.6% of respondents answered winter, while the summer was selected by 11.9% of the workers (Q-2.3). In addition, during the winter the thermal environment of the workplace is classified as colder (Q-2.22), and the mean value of 7.97 and a percentage of 33.8% in the highest level accurately represent this occurrence (*vd*. Fig. 3 (Q-2.22)). This fact is more pronounced among women which present a higher mean value ($p<0.05$). These results also suggest uncertainty in the decision of selecting the colder thermal environment during winter or the exposure to high temperature differences during summer.

Regarding the preventive measures against cold the majority of the participants (80.6%) report only one action and adding more cloths is the first and usual choice (75.1%). All the other possibilities have levels of response lower than 10%. Since multiple answers (7.5%) were permitted in this question, the relative percentages are calculated taking into account the total number of votes (173).

The characterization of the personal thermal state and the assessment of the thermal environment, namely in terms of thermal perception and personal tolerance is shown in Fig. 3 (Q-2.9, Q-2.10, Q-2.19 and Q-2.20). The results in terms of feeling cold are distributed across the scale, with 48.1% of the votes in the 1

to 5 range and 51.3% between 6 and 10 (*vd.* Fig. 3 (Q-2.9)). The highest percentage corresponds to level 5 with 29.4%. The results about the tolerance to cold (*vd*. Fig. 3 (Q-2.10)) are also distributed (50.0% and 49.4%, respectively in the 1 to 5 and 6 to 10 ranges) with the highest percentages in the middle levels. This indicates that the workers are acclimatised to the cold. In these two questions the mean value is higher among women ($p<0.05$), showing that women feel colder and tolerate less the cold than men.

The assessment of the thermal perception of the work environment (*vd.* Fig. 3 (Q-2.19)) shows that 29.4% and 70.0% of the results are in the 1 to 5 and 6 to 10 ranges, respectively. Regarding the personal tolerance the majority of the votes (66.3%) are located in the 6 to 10 range, suggesting that these workers tolerate the thermal environment quite well, but there is still a significant minority (31.9%) who does not (*vd*. Fig. 3 (Q-2.20)).

The degree of global thermal comfort and the occurrence of draughts in the workplace are assessed in Fig. 3 (Q-2.11 and Q-2.21). The degree of comfort is acceptable since 45.0% of the votes are in the 1 to 5 range and 52.5% in the 6 to 10 range. In addition, the results about the draught risk show that there is a higher response rate (62.5%) in the 6 to 10 range, with level 10 most quoted (23.8%) and that the feeling of the occurrence of draughts is higher for women ($p<0.05$) with a mean value of 6.92 while the corresponding value for men is 5.54.

The characterization of the thermal environment of the place where the rest period is spent is analyzed in Fig. 3 (Q-2.18). The number of answers reached 153 despite the 73 workers that indicate the existence of rest periods. The mean value was equal to 6.38 and the levels most marked were number 8 (22.5%) and 5 (16.3%), indicators that suggest acceptable conditions during the rest period.

The assessment of the acclimatization to the cold after a prolonged stop or after holidays (*vd*. Fig. 3 (Q-2.23)) shows a higher percentage of votes (58.1%) in the 6 to 10 range with a predominance of votes on level 5 (18.1%). The mean value was 6.18. A higher mean value was obtained for women ($p<0.05$), but both mean values (6.35 for women and 5.24 for men) show that both genders have to deal with some kind of difficulties during the first working days.

The last question is concerned with the global assessment of the thermal environment (*vd.* Fig. 3 (Q-2.24)). The answers are divided between the 1 to 5 and 6 to 10 ranges (40.6% and 58.1%, respectively), with a higher percentage in the 6 to 10 range, being level 7 the most quoted (20.0%).

Personal Protective Clothing

The assessment of the cold protective clothing through the subjective survey represents the issue of the questionnaire that can be related to the field evaluations and to the application of the *IREQ* index. The subjective survey shows that the waistcoat (37.7%) and the coat (22.9%) are the most common protective garments. This is in accordance with the data collected in the field by specific questionnaires. However, it is important to point out that 3.8% of the workers did not respond, while 50.0% signed up for one garment and 46.2% for more than one piece of cloth. The results about the personal protective clothing assessment in ergonomic and thermal protection terms (*vd*. Fig. 3 (Q-2.12, Q-2.13 and Q-2.14)) show mean values around 5 and that level 5 was always the most voted.

4 Discussion

Considering the calculations performed with ISO Technical Report[17)] for reference, the results of the *IREQ* index clearly put in evidence that, from a global point of view, the recommended pattern represented by values within the clothing regulatory zone ($IREQ_{minimal} \leq I_{clr} \leq IREQ_{neutral}$), corresponds to only 12% of the workplaces. Unfortunately, this statement is in close connection with the conclusions obtained by the European Observatory of Risks and the European Agency for Safety and Health at Work where the thermal environment is recognized as an emergent risk[35, 36)]. The analysis of the results obtained with ISO 11079 Technical Report[17)] and ISO 11079 International Standard[20)] (*vd*. Fig. 1) puts in evidence the difference between both *IREQ* values. This is an interesting detail and that difference is higher with[20)], being approximately 0.3 *clo* and 0.2 *clo* if [17)] is considered. Despite higher differences obtained with the last version of the *IREQ* index, the clothing regulatory zone is in fact a narrow band that does not allow many garment options. For instance, the thermal insulation of a simple t-shirt is enough to fulfil such differences. The relationships between *DLE* and *IREQ* for the cases with insufficient clothing insulation ($I_{clr} < IREQ_{minimal\ or\ neutral}$) (*vd*. Fig. 2) show that the higher values of *IREQ* are seen to correspond to the lower *DLE* values, conclusion that is in good agreement with what might be expected: the coldest workplaces are prone to less favourable working conditions and therefore the freezing chambers should be addressed with special care. In fact, all the freezing chambers show an I_{clr} lower than $IREQ_{minimal}$, which means that the selected clothing ensembles do not provide adequate insulation. The results also suggest that the choice of the clothing, and therefore the clothing insulation, is directly related to the air temperature, so the highest I_{cl} values correspond to the coldest stores.

The discussion of the results of the questionnaire raises several topics that will be presented following the sequence shown in the previous section. In terms of *General Aspects*, a global picture of the food distribution sector shows that the working force is characterized by a young population, particularly women with a medium-length professional career. The results regarding the number and duration of the rest periods are important and clearly enhance that a special attention is due to this topic. In fact, the advantages related to the introduction of rest periods in the work shifts are yet to be explored and this simple preventive measure show outcomes that are usually associated to advantages rather than disadvantages. This is a method of great concern that is raised by international standards[37)]. The permanency in the coldest workplace represents a critical issue that should be compared with the *DLE* values suggested by the *IREQ* index. Whenever possible the permanency in the coldest workplace should be less than the duration limited exposure. For the majority of workplaces the *DLE* value is less than 1 hour and less than 3 hours for the remaining workplaces. This cross analysis between the field and the subjective assessments is very important to support preventive measures. In fact, in the case of discrepancies, a special attention is required. The other exposure periods specified in the questionnaire (3 to 5 and 5 to 8 hours) are associated to the workers that develop a variety of tasks in similar thermal environments which do not require a shift in the cold chambers. Another important issue is related to the activities that call for a high physical effort. When this occurs it may lead to the appearance of sweat and its clothing accumulation during more active phases which can result in an insufficient thermal protection during other phases[38]. The last topic of the *General Aspects* is related with repetitive occupations. The results of the subjective assessment clearly highlight a repetitive activity, which combined with the cold thermal environment and occupations typically performed by a single individual, which were often identified in the field survey, may indeed increase the development of critical workplaces. The relationship between repetitive tasks and musculoskeletal disorders is well known in the case of moderate environments. In cold indoor work a part of the musculoskeletal complaints may be due to the combined effects of cold exposure and repetitive work[39, 40)] which may result in an increased occurrence of carpal tunnel Syndrome[41)] increased muscle strain and fatigue[42)]. Therefore, when dealing with occupational cold thermal environments, the *Health Effects* should never be neglected. Moreover, the results of the present study on this matter recommend a medical supervision of individuals frequently exposed to cold environments.

The assessment of the *Thermal Environment* and related topics is based on several questions. Firstly, because cold thermal environments represent the main topic of the study, it is important to evaluate if the outdoor environmental conditions affect the indoor environment of the workplaces. The results confirm this reality since the thermal environment of the workplaces is classified as colder in the winter. The

preventive measures against cold are an issue that should be known by the workers. From the results of the questionnaires and the field observations, we can conclude that workers engaged in cold work did not receive a basic introduction to the specific problems of cold. Accordingly, more information should be given about physiological and subjective reactions, health aspects, risk of accidents, and protective measures, including clothing and first aid[44)]. Otherwise, with the help of standards, it is easy to find guidelines for preventive measures and the management of cold related risks based on the principal of continuous improvement[11)]. One of the important topics is training, namely in terms of the evaluation of thermal perception. For instance, the results show that the sensation of cold was reported but during the field evaluations the opinions state that the thermal environment is even colder. The linear correlations Q-2.9 *vs* Q-2.19 and Q-2.10 *vs* Q-2.20 were assessed by Spearman's rho. Both results were statistically significant ($p<0.01$) and the Spearman's rho coefficient was equal to 0.557 for the correlation Q-2.9 *vs* Q-2.19 and equal to 0.378 for the correlation Q-2.10 *vs* Q-2.20, which shows the same trend variations. Based on the results about the degree of global thermal comfort and the occurrence of draughts in the workplace (*vd*. Fig. 3 (Q-2.11 and Q-2.21) it can be stated that the degree of local discomfort is still acceptable. As stated by[44)], most of the forklifts used in large cold stores are opened and driving creates a relative wind speed which increases body cooling. In addition, the work itself is rather light associated with a low metabolic heat production. Thus, whenever possible, the use of closed forklifts is recommended. The acclimatization after a prolonged stop is another important topic and the results suggest that this issue should be carefully considered in order to adopt programs of growing exposure periods, particularly for those which have to be exposed to the lower temperatures during the work shifts. The last question of the questionnaire deals with the judgment of the thermal environment of the workplace in a wide perspective. The subjective results show that the thermal environment is considered globally acceptable which is in disagreement with the opinion stated by several workers in informal interviews carried out during the field evaluations. In these casual dialogues the workers reported that they were generally dissatisfied with the thermal conditions of the workplace and, whenever possible, they try to change the kind of tasks performed or even leave and look for another job elsewhere. According to [35, 36)], this discomfort with the thermal environment of the workplace represents an emergent risk that should justify a special concern among all the people involved.

Finally, the *Personal Protective Clothing* was assessed by several questions. The results about the availability suggest a wide distribution so the use of protective clothing in different industrial environments represents the daily practice for the economic group that participated in the present study. In fact, in the industrial units that were visited the awareness of the risks of cold exposure has become a natural attitude. However, the results of the *IREQ* index put in evidence a clear disagreement between the

ensembles daily used by the workers and the clothing insulation requirements needed to continuous or intermittent exposures to the most severe thermal environments of the food distribution activity sector. Moreover, the results suggest that workers are not satisfied with the available cold protective clothing. This conclusion about the inadequacy of the clothing ensembles is thus in accordance with the indications of the *IREQ* index, which highlight that the selected ensemble provided more than enough insulation in the manufacturing workplaces while in the freezing chambers the available ensembles is far from being sufficient. Thus, a readjustment of the protective clothing is clearly needed to fulfil the desirable requirements and a special attention must be given to personal protective equipment since an important increase in its performance may indeed be achieved. Due to the fact that both field measurements and subjective assessment approaches seem to led to the same conclusion, Spearman's rho and Principal Component Analysis (PCA) tests were carried out between questions Q-2.12, Q-2.13 and Q-2.14. The Spearman's rho coefficients were equal to 0.762, 0.726 and 0.767 for the correlations Q-2.12 *vs* Q-2.13, Q-2.12 *vs* Q-2.14 and Q-2.13 *vs* Q-2.14, respectively, with statistical significance ($p<0.01$). The first component of the PCA test explained 83.73% of the total variance which suggests that it can be used as an index for this group of questions. It was also observed that the question's loadings for the first component were approximately equal and around 0.9, therefore a simple mean of those three questions would be an adequate index.

5 Conclusion

The present paper focuses the occupational exposure to cold thermal environments in the food distribution activity sector through field measurements and a subjective assessment. The results obtained with ISO/TR 11079[17)] and ISO 11079[20)] show that for a large percentage of the workers the available clothing ensembles are inadequate for the environmental conditions to which they are exposed. Frequently, the selected ensembles provide more than sufficient insulation, while in freezing chambers the thermal protection provided by the selected clothing ensembles is clearly insufficient. The selection of clothing according to the activity and to the working environment is therefore a matter that should be considered with care.

The subjective survey shows that the food distribution sector is characterised by a young population, mainly women with a short-length professional career. Surprisingly, it was observed that the cold exposure required in this activity sector is generally guaranteed by women who performed all the work necessary in the cold chambers. An analysis by gender have shown statistically significant results in terms

higher feeling of cold and less tolerance to cold among women. The reported health problems should be relevant enough to call the attention of occupational health professionals, in order to promote an active medical supervision of individuals continuously exposed to cold environments. The extensive distribution of cold protective clothing, the absence of rest periods, the relative short permanency in the cold chambers and the generally acceptable thermal environment of the workplaces represent some of the important conclusions of the present results.

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Table 1: Questions of the questionnaire

PART – 1			
Ref	**Q – Question**	**Ref**	**Q – Question**
Q-1.1	Age *18-25, 26-35, 36-45, 46-55, > 55 years old*	Q-1.2	Gender *Female, Male*
Q-1.3	Do you have any of the following health problems *Cardiovascular (Hypertension, Bradycardia, Angina pectoris, Peripheral vascular disease)* *Respiratory (Coughs, Rhinitis, Nose bleeds, Asthmatic episodes, Chronic obstructive pulmonary disease, Bronchitis)* *Metabolic (Thyroid diseases, Diabetes mellitus)* *Other effects (Diuresis, Arthritic and Musculoskeletal disorders)*		
PART – 2			
Ref	**Q - Question**	**Ref**	**Q - Question**
Q-2.1	Which is your workplace? *Storehouse, Cold chambers, Delicatessen, Expedition/reception, Fruits and vegetables, Milk-food products, Fish market, Bakery/confectionary, Meat cutting up room, Butchery, Manufacturing workplace, Other*	Q-2.2	How long have you been working in the present activity? *< 1 year, 1-3, 3-5, 5-10, 10-20, > 20 years*
Q-2.3	Which is the most difficult period of the year to perform your activity *Spring, Summer, Autumn, Winter*	Q-2.4	When you feel cold in the workplace, which measure(s) do you adopt? *Add more cloths, Start a rest period, Change workplace, Increase the physical activity, Go to a more comfortable workplace, None, Other*
Q-2.5	Which cold protective garments do you have available: *Gloves, Boots, Hood, Coat, Waistcoat, Trousers, Respiratory protective mask, Other*	Q-2.6	During the work day (8 hours), beyond the breaks for the meals, how many rest periods do you have? *0, 1-2, 3-4, 5-6, > 6*
Q-2.7	What is the average duration of the rest period(s)? *< 15 min, 15-30, 30-45, 45-60, > 1 hour*	Q-2.8	If your activity requires your presence in more than one place, how long do you stay in the coldest? *< 1 hour, 1-3, 3-5, 5-8 hours*
⇓ Questions 2.9 to 2.24 are based on a 10-level judgment scale: *1, 2, 3, 4, 5, 6, 7, 8, 9, 10* ⇓			
Q-2.9	Do you feel cold in the workplace?	Q-2.10	How well do you tolerate the cold in the workplace?
Q-2.11	Do you feel comfortable in the workplace?	Q-2.12	The cold protective clothing is adequate?
Q-2.13	The cold protective clothing is sufficient?	Q-2.14	The cold protective clothing is comfortable?
Q-2.15	During your activity, do you often sweat?	Q-2.16	Classify your activity regarding the physical demand:
Q-2.17	Is your activity repetitive?	Q-2.18	Do you feel satisfied with the thermal environment of the place where you spend the rest period?
Q-2.19	The thermal environment of the workplace is cold?	Q-2.20	The thermal environment of the workplace is tolerable?
Q-2.21	Do you often feel draught in the workplace?	Q-2.22	Is the thermal environment of the workplace colder during the Winter?
Q-2.23	After a prolonged stop (vacations, disease, …) do you feel any difficulty in adapting to the thermal environment of the workplace?	Q-2.24	What is your general judgment regarding the thermal environment of the workplace?

Table 2: Food distribution activity sector: Mean and Standard Deviation values (Mean±SD) of the measured physical parameters and estimated metabolic rates and intrinsic thermal insulation of clothing

	T_a [ºC]			**T_g [ºC]**	***rh*, %**	**v_a [m/s]**	***M [W/m²]***	***I_{cl} [clo]***
	Mean±SD	Max	Min	Mean±SD				
F	-17.4±3.3	-10.0	-20.4	-18.1±3.4	94.1±2.2	0.49±0.21	151.0±0.0	1.48±0.02
R	4.5±2.5	9.2	1.4	3.9±2.7	86.2±6.6	0.31±0.44	160.9±24.3	1.22±0.19
M	12.0±2.1	16.1	3.9	12.3±3.1	69.9±16.9	0.09±0.08	153.1±21.2	1.09±0.04
F – Freezing chambers; R – Refrigerating chambers; M – Manufacturing workplaces								

Table 3: Detailed results of evaluated workplaces according to ISO 11079 (2007)

			Level of Strain					
			Minimal			**Neutral**		
Code of the workplace	Type of workplace	I_{cl} [*clo*]	*IREQ* [*clo*]	Required I_{cl} [*clo*]	*DLE* [hours]	*IREQ* [*clo*]	Required I_{cl} [*clo*]	*DLE* [hours]
FD1_5	Freezing chamber	1.45	2.0	2.2	0.8	2.3	2.6	0.5
FD2_2	Freezing chamber	1.47	2.1	2.3	0.7	2.4	2.7	0.5
FD2_3	Refrigeration chamber	1.11	0.9	1.0	> 8	1.2	1.4	1.7
FD2_5	Refrigeration chamber	1.11	0.9	1.0	> 8	1.2	1.3	2.7
FD3_3	Freezing chamber	1.46	1.6	1.7	2.6	1.9	2.0	1.0
FD3_6	Freezing chamber	1.51	2.0	2.2	0.9	2.3	2.5	0.6
FD4_3	Freezing chamber	1.50	2.0	2.2	0.8	2.3	2.6	0.6
FD5_3	Freezing chamber	1.46	2.0	2.2	0.8	2.3	2.5	0.6
FD5_2	Refrigeration chamber	1.02	0.7	0.7	> 8	1.0	1.0	> 8
FD1_1	Refrigeration chamber	1.11	0.8	0.9	> 8	1.1	1.2	> 8
FD1_3	Refrigeration chamber	1.46	0.8	0.8	> 8	1.1	1.1	> 8
FD2_1	Manufacturing workplace	1.08	0.5	0.5	> 8	0.8	0.8	> 8
FD3_4	Refrigeration chamber	1.12	0.4	0.4	> 8	0.6	0.7	> 8
FD4_2	Refrigeration chamber	1.55	0.7	0.7	> 8	1.0	1.0	> 8
FD5_4	Refrigeration chamber	1.27	0.5	0.6	> 8	0.8	0.9	> 8

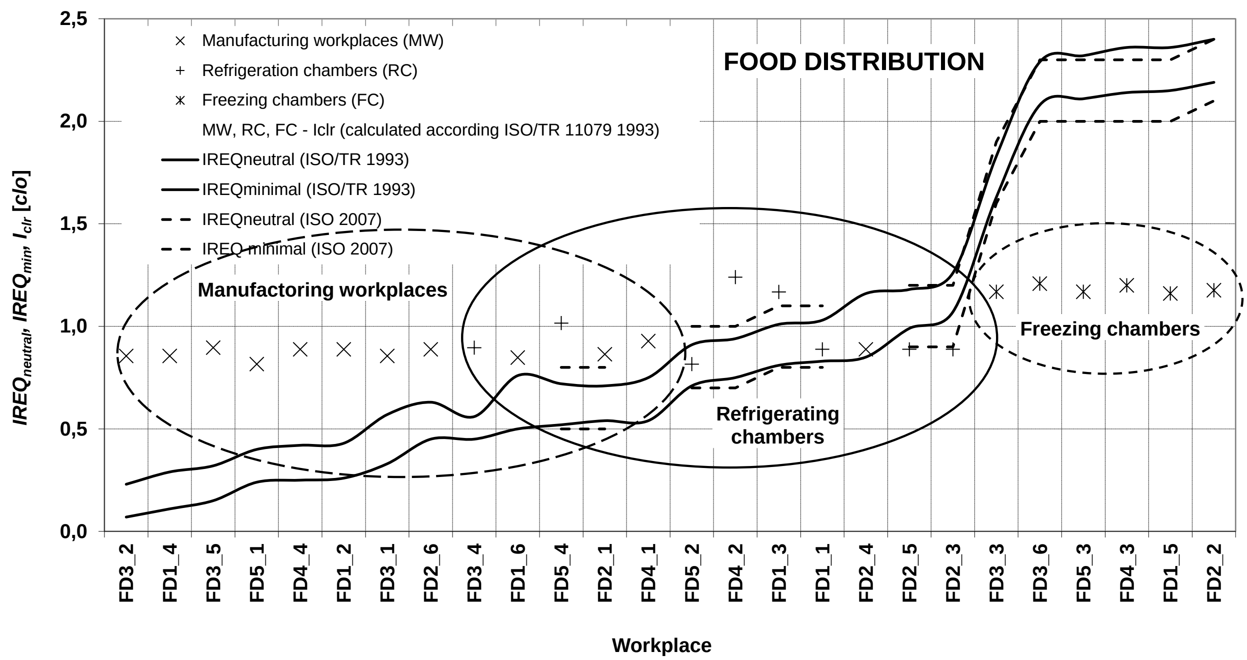

Fig. 1: Values of the required clothing insulation ($IREQ_{neutral}$, $IREQ_{minimal}$) and resultant clothing insulation (I_{clr}) in each workplace

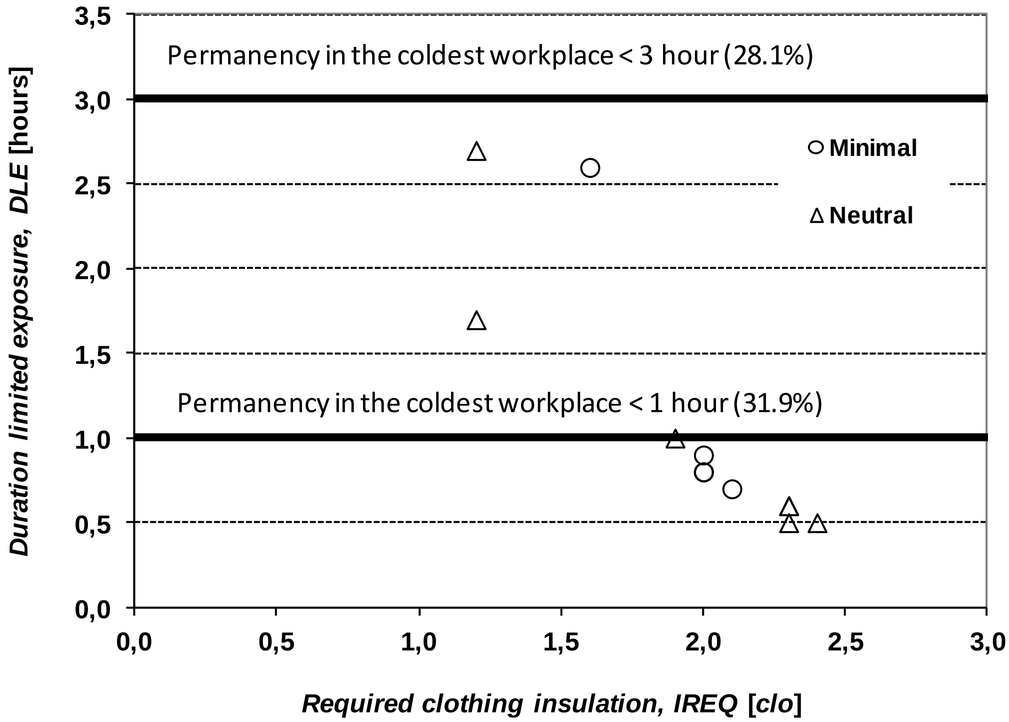

Fig. 2: Duration limited exposure (*DLE*) *vs* required clothing insulation (*IREQ*)

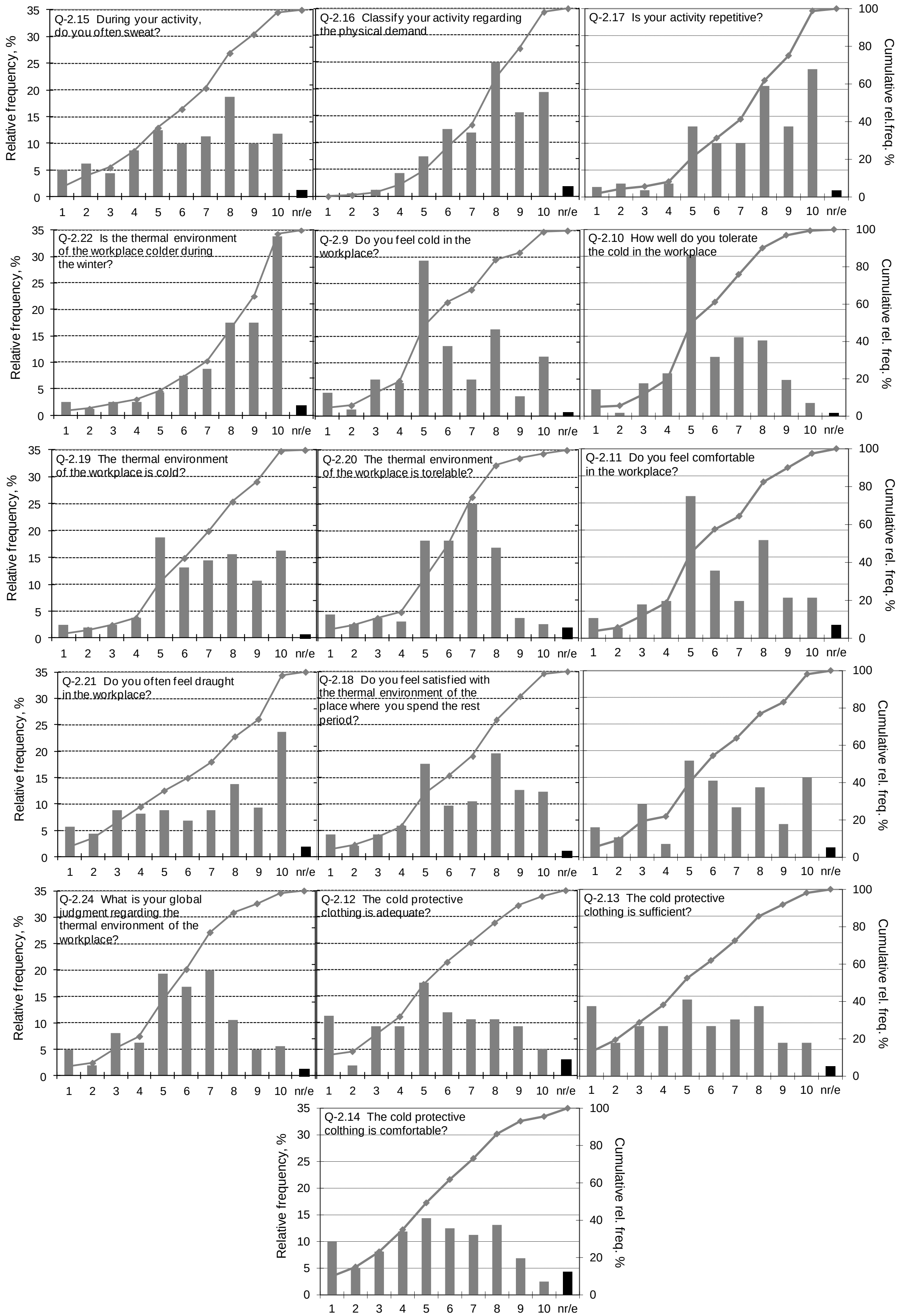

Fig. 3: Relative frequencies and cumulative relative frequencies of the questions of the questionnaire based on the 10-level judgment scale.