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Creating PRODUCTIVE Workers in Industrial Context from the Definition of Thermal Comfort

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Abstract

The human action among environment concerns and countries development is being debated by several authors. Thermal comfort is an extremely broad concept directly related to ergonomics, energy buildings consumption and workers' performance. The present paper intends to analyse the thermal environment inside of a Portuguese manufacturing metalworking industry in order to understand its influence in worker's performance and well-being. For this purpose, two types of studies were conducted: analytical and empirical. The analytical exploration regards the indoor thermal environment study concerning two thermal indexes: EsConTer and THI. The empirical exploration consists in workers' thermal sensation study, regarding a thermal colour scale based in ASHRAE seven-point thermal scale. Therefore a measuring instrument was used, 'Testo 435-4', to collect air temperature (ºC), air relative humidity (%) and wet bulb temperature (ºC) data. The EsConTer index was the most surprising applied method since it showed itself capable to describe the thermal environment of an industrial space due to its correlation with THI, and at the same time adequate to define workers' thermal sensation. Moreover, the authors consider thermal environment studies in workplaces an important aspect to improve the productivity of workers in business contexts.

Key words: *Ergonomics, Thermal comfort, Thermal sensation, Work environment, Workers*

1.INTRODUCTION

We live in a world filled with a consuming and demanding society concerned about global causes. The environmental preoccupations are one of those which are gaining ground in every field of investigation. Currently, to "be green and lean" is not just a new competitive expertise but a trend and statement.
Climate changes are one of the most challenging global issues, which are in part caused by the human-being action. Historically, they are related to the economic development of the countries, mostly as consequence of the industrial growth of developing countries. In fact developing countries, agreeing with Jauregui (1999, referred by [1]) are going to be the most populated (90%) areas between 2004 and 2025. Thus, under these circumstances which greatly affect humans' quality of life, becomes essential to create conditions inside buildings to ensure security, health, quality and comfort.
Nowadays, the industrial context is strongly characterized by uncertain environments, extreme competition and constant and unexpected changes where productivity is one of the most important goals to achieve. Consequently, workers are one of the most important keys of a company success, as Henry Ford said "you can take my factories, burn up my buildings, but give me my people and I'll build the business right back again".
In this sense and regarding that people notably spend most of their time in their workplaces, the existence of a positive relation between workers and workplace environment becomes imperative [2, 3].
The scientific field of ergonomics, often represented by Health and Safety department, has a crucial role in workers well-being recognition in workplaces [4]. This field of studies is, according to Wisner (1982, referred by [5]), the scientific knowledge related to human being necessary to provide tools, machines and displays that can be used with the maximum comfort, security and efficiency.
Associated to indoor environments and ergonomics arises the energy consumption management issue. Yang *at al*. (2003); Pérez-Lombad *at al*. (2008); Morosan *at al*. (2010) [referred by 6] report that the buildings' energy consumption is about 40% of the energy consumed around the world. Hence, a more conscious and rational use of the energy must be done taking into consideration the understanding of the

interaction between the occupants of a space and the environment of that space [7, 8].
According to Bluyssen *at al*. [9], there are a lot of studies that demonstrate a strong relation among comfort, health, and environment control with productivity in workplaces. The American Society of Heating, Refrigerating and Air Conditioning Engineers (ASHRAE) refers that the productivity of a person can decrease 1.8%, in each ºC highest to 27ºC [10].
Regarding Huizenga *at al*. (2006, referred by [11]) thermal discomfort is considered the major cause of dissatisfaction in workplaces.
The study of thermal environment belongs to Ergonomics and has been the target of diverse studies. This subject research has shown that by controlling thermal environment conditions inside a building, higher levels of workers' satisfaction and productivity can be achieved while the number of work accidents and workers' fatigue are reduced [4].
According to Lopes (2008, referred by [12]) the study of thermal environment should be focused in two different aspects; the relation between the workplace thermal environment and safety and the relation between workers' productivity and the workplace thermal environment surround.
The literature has revealed that the most common methodology used to explore this field of studies lies in analytical methods based on thermal indexes. According to several authors ([12, 13]), these analysis approach is the biggest issue in thermal comfort studies as they do not take into consideration workers' (real) thermal sensation during work activity (while exposed to thermal environment).
Hence, the purpose of this paper is to show the influence of thermal environment conditions in a workplace and its implications on workers' efficiency and well-being, applying both analytical and empirical methods. Accordingly, the dynamic of the thermal environment in an industrial space was evaluated in order to identify thermal islands (thermal critical areas). In this sense, data of air temperature (ºC), air relative humidity (%) and wet bulb temperature (ºC) was gathered and after interpreted by thermal indexes. Afterwards, the empirical study (survey) was made aiming to understand workers' thermal sensations in the defined thermal islands and thus recognize the thermal stress impact in workers' behaviour and performance.

2. ABOUT THERMAL COMFORT

The study of thermal comfort has gained importance since Fanger's [14] investigations, being nowadays an extremely broad concept applied in industry, schools, hospitals, transportation, construction, among others [5].
According to Emmanuel [1], thermal comfort is a complex reaction to different parameters, environmental and personal, being defined as a person's condition of mind which expresses satisfaction towards the thermal environment [15, 16]. Provided that, thermal comfort is a very subjective sensation, i.e., regarding the personal aspects each person has her own sensation of thermal comfort. As an illustration a person from a tropical area does not have the same thermal sensation as a person from a frozen area [6]. In light of this, thermal comfort is defined by different intervals in literature.
Additionally, to study thermal comfort is necessary to understand the limits where thermal discomfort occurs. Thermal discomfort is mentioned in the literature as thermal stress and corresponds to a person's sense of unease when exposed to extremely hot or cold thermal environments, or thermal discomfort located in a particular part of the body [5, 16]. Regarding to Costa *at al*. [17] thermal stress related to hot environments is injurious to health and is associated to behavioural changes like humour oscillations, distractions, fatigue, demotivation, absenteeism, dehydration, demineralization, among others.

2.1 Thermal Environment

Thermal environment is characterized as a set of thermal variables surrounding a person which may influence her directly or/and indirectly, such as air temperature (ºC), air velocity (m/s), air relative humidity (%), among others.
According to Cox (2005, referred by [9]) a healthy environment can be found when the combination of physical, chemical and biological proprieties do not cause or aggravate none of the workers diseases and ensure high levels of comfort, contributing for workers best performances while they execute their functions/tasks.
Citing Yao *at al*. [18] indoor air temperature is seriously influenced by outside environment conditions. As a result, it is required to study the outside thermal environment while studying environmental parameters inside buildings.
Regarding hot thermal environments, the factors that higher affect its criticality are temperature, humidity, radiant heat and air velocity [17]. As well, citing Costa *at al*. [17], the combination of heat and humidity can dangerously affect a person's health, mostly during summer season.

2.2 Thermal Sensation

The human-being thermal perception is recognized by their thermal sensation, a reaction from the human organism caused by the environment surrounding [18].
According to Zingano (2001, referred by [19]) thermal sensation is transmitted by skin temperature- the reference temperature of thermal comfort sensation.
Under normal health and comfort conditions, human body keeps an internal temperature of about 37±0,8ºC ([12, 19]), as human-beings are homoeothermic- balance between heat internal production from metabolism and its dissipation to the surrounding environment ([12, 6]).
Beyond thermal parameters described in the previous chapter (thermal environment), thermal sensation is influenced by personal factors which as well, affect the answer of a person to the surrounding environment. Personal factors can be described as physical, psychological, physiological and cultural, more specifically age, gender, eating habits, clothing, metabolism, among others.

Regarding Fanger (1972, referred by [18]) the variables which mostly affect human-beings thermal sensation are clothing, air temperature, air velocity, pressure and water vapor in atmosphere.
The human organism is always interpreting information from the surrounding environment by its sensors, giving human-being the capacity to adjust him-self to surrounding stimulus. For example, and citing Costa *at al*. [17] when it comes to extremely hot environments, skin sensors verify the temperature differential between human body and skin and send this information to hypothalamus, which afterwards triggers a vasodilatation process. The vasodilatation allows a larger quantity of blood flowing through superficial vessels, increasing skin temperature and heat dissipation through convection and radiation. In this case the mechanism intensifies heat loss to environment by transpiration.
According to Yao *at al*. [18] there are three human adaptation types: physiological, behavioral and psychological, shown in Figure 1.

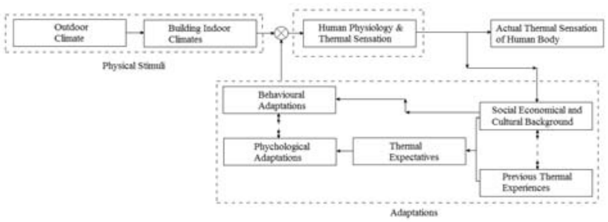

Figure 1. Adaptive model (taken from [18])

- The physiological adaptation can occur through genetic adaptation, or through acclimatization (the state caused by a physiological adaptation process which increases the tolerance of a person to certain environments during a long period of time [12]). Accordingly, some aspects of physical adaptation, like sweats and vasodilatation, regulate the core temperature of the human body.

- The behavioral adaptation is the most interesting type of adaptation, representing the conscious or unconscious actions taken by a person during her daily routine. Regarding this adaptation type, three subtypes can be distinguished: personal adaptations, such as cloth changing, window opening/ closing, consumption of hot/cold drinks, etc.; technological adaptations related to the act of switch on/off a warming/cooling system and cultural adaptations, like to take a nap after lunch [18].

- The psychological adaptation is the most difficult adaptation to be measured, being connected to perception and reaction changing to a sensorial stimulus. The perception and reaction changes occur based on personal past thermal experiences and expectations- when human body quickly and frequently faces a particular thermal stimulus, tends to be less sensitive to it.

Also, citing De Dear *at al*. (1997, referred by [8]), individuals exposed to closed spaces and seriously controlled by air conditioning systems are twice sensible to temperature changes than individuals exposed to natural ventilated environments (windows). Nevertheless was verified that in indoor spaces provided with both ventilated systems - Heating, Ventilation, and Air Conditioning (HVAC) and natural ventilation -, 23% of the windows are open during summer while HVAC are also switched on [7, 18]. This fact shows that even though work places are provided with all the displays and tools to offer good thermal conditions, they are not being controlled and well managed. Besides that, also normative norms are not being well applied. So, because of these reasons a strong loss of energy occurs instead of creating indoor neutral environments which would confer comfort to a larger number of individuals and would allow a balance between metabolic heat production and heat exchanges among surrounding air [12].

2.2.1 *Human body thermal balance, metabolism and clothing insulation*

The thermal balance translates the human body temperature trough skin mean radiant temperature, considering the human being in a stationary state, as show in the forward expression [12]:

$$M - E_d - E_s - E_r - L = R + C = K \quad (1)$$

where, M - heat metabolic production (metabolic Energy); E_d - heat loss trough water vapour diffusion from skin; E_s - heat loss trough sweat evaporation from skin surface; E_r - heat loss latent in breathing; L - sensitive heat loss from breathing; R - heat loss trough radiation from clothing external surface; C - heat loss trough convection from clothing external surface; K - heat transference from skin surface until clothing external surface.
Following the thermal balance expression, hot thermal environments are characterized by a positive thermal balance [17] and metabolism and clotting insulation are crucial to thermal comfort studies.
Regarding Rodrigues (1978, referred by [13]) the metabolism is defined as a set of biochemical processes which occur in human organism when it creates living tissue from nutritive substances, transforming them into energy.
The metabolic rate, represented by M, means the energy consumed/used by a human being during certain period of time or the quantity of heat produced per unit area of skin. This rate can be expressed in W/m^2 or met. Regarding ISO 7730 [16] one (1) met corresponds to a heat loss of about $58W/m^2$, associated to a resting state of a European male with about $1{,}8m^2$ of skin surface area (a European women in average has about $1{,}6m^2$ of skin surface area) [4].
Two types of metabolism can be distinguished, the metabolism of activity and basal metabolism. The

metabolism of activity results from the physical effort of human-being activity whereas basal metabolism is considered a standard value equal to $45 W/m^2$. Basal metabolism also corresponds to a human-being resting state deprived of external thermal influences and with neutral clothing [5, 12]. Citing Rodrigues [13] a metabolic rate corresponding to an active individual will be higher the higher is the external work, as shown in table 1. The metabolism of an individual can be 20 times higher than basal metabolism [12]. Moreover, metabolic variations fluctuate with corporal area (m^2)- which is influenced by height (m) and weight (kg), concerning to DuBois (1916, referred by [12]) studies.

Table 1. Metabolism (adopted from [5])

Activity	Metabolism (W/m^2)
Lying down	46
Sitting and resting	58
Sedentary activity	70
Up, light activity	93
Up, average activity	116
Great activity	174

The clothing variable, as said and shown previously brings also a significant contribution to thermal comfort since it illustrates the adequacy level of work clothing, regarding imposed work thermal conditions. In order to analyze this variable, clothing thermal resistance is evaluated [13]. Clothing thermal resistance is expressed by Clo. One Clo (1Clo) corresponds to 0,155 m^2. ºC/W, interpreted by Rodrigues [13] as the offered thermal resistance from each 0,155m^2 of the worn clothing when covered skin cools 1 ºC because of 1 W of heat transference to clothing external surface.

Table 2. Clothing thermal resistance (adopted from [16])

Type of clothing	Thermal resistance - Clo
Panties	0.03
Panties & bro	0.03
Socks	0.02
Long sleeves	0.30
Trousers normal	0.25
Light jacket	0.25
Shoes	0.04
Scarf	0.05
Polo	0.20
Light trousers	0.20
Thick sweater	0.35

Clothing thermal resistance is influenced by air temperature, external work (related to metabolic rate and individual activity [13]) and clothing features. Its values can be consulted in ISO 7730 [16]. Some examples of thermal resistance values can be visualized in table 2.

2.3 **About some Thermal Indexes**

According to the literature many indexes are being used in order to explore this field of studies.

Predicted Mean Vote (PMV) and *Predicted Percentage Dissatisfied* (PPD) are the most common indexes used by diverse authors. The first one, PMV, was created by Fanger [14] and predicts the thermal comfort mean response of a large group of people exposed to certain thermal conditions during a long period of time [6] according to the ASHRAE seven-point thermal sensation scale. The ASHRAE seven-point thermal sensation scale is based on heat balance of the human body and represents the human thermal perception trough seven points: '+3' (hot), '+2'(warm), '+1'(slightly warm), '0'(neutral), '-1'(slightly cool), '-2'(cool), '-3'(cold).

PMV index is defined by six parameters: metabolic rate, clothing insolation, air temperature, mean radiant temperature, air velocity and air humidity, as shown in table 3 [6]. The first two variables are defined by standard tabled values and the others by measuring instruments.

Table 3. PMV parameters (adopted from [6])

Parameters	Symbol	Limits	Unit
Metabolic rate	M	0.8-4.0	Met (W/m^2)
Clothing insulation	Icl	0-2	Clo (m^2 ºC/W)
Air temperature	T	10-30	ºC
Mean radiant temperature	T_r	10-40	ºC
Air velocity	v	0-1	m/s
Air relative humidity	RH	30-70	%

The PMV calculation equation is:

$$PMV = \left[0.303 e^{(-0.036 M)} + 0.028\right] \cdot L \qquad (2)$$

where, L represents human body thermal charge (W/m^2) and M the metabolic rate (W/m^2).

The PPD index is related to PMV by PMV-PPD model, but unlike to PMV it represents the percentage of individuals dissatisfied exposed to certain thermal conditions and is expressed by the following equation:

$$PPD = 100 - 95 e^{\left[-\left(0.03353 PMV^4 + 0.2179 PMV^2\right)\right]} \qquad (3)$$

The advantage, citing Yao *at al*. [18], of PMV-PPD model is the large set of parameters analyzed.

In a utopic situation and regarding Liang & Du [20] it is expected a PMV equal to zero, combining optimal hygrometric and personal parameters. Nevertheless, this scenario is impossible to achieve, as it would mean that 100% of the individual in a group felt pleased under surrounding thermal conditions. So, concerning this reflection it is necessary to consider admissible limits to PMV and PPD indexes which characterize an area as a comfort zone, namely:

- A category: PPD<6% and -0.2<PMV<+0.2;
- B category: PPD<10% and -0.5<PMV<+0.5;
- C category: PPD<15% and -0.7<PMV<+0.7.

EsConTer and Temperature-Humidity index (THI) represent other types of thermal indexes described in literature. The EsConTer index was created by Talaia and Simões [21] and is classified as a thermal scale (Ter) based on a colour scale (Es) which valorises ASHRAE seven-point thermal sensation scale [22] and the thermal sensation of the occupants (Con). The calculation equation of EsConTer index is:

$$EsConTer = -3.75 + 0.103(T + T_w) \qquad (4)$$

where, T - Air temperature (°C); Tw = temperature of the wet bulb (ºC).
In the light of ASHRAE scale, the results of EsConTer index follow the same scheme, although represented by a colour scale from '-3' (dark blue colour - thermal sensation: very cold) to '+3' (dark red colour - thermal sensation: very hot), as shown in Figure 3.

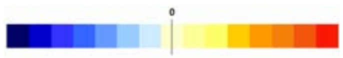

Figure 2. Colour scale to thermal sensation

The THI index was created by Thom [23] and later modified by Nieuwolt [24], given by the equation:

$$THI = 0.7T + T(RH/500) \qquad (5)$$

where, T - air temperature (°C); RH - relative humidity (%).

As mentioned in Thermal Comfort chapter, thermal comfort is represented by different intervals in literature, so in this particular case study THI limits adopted by Talaia *at al*. [25] were followed, as shown in table 4.

Table 4. Thermal sensation limits

THI	Thermal sensation
THI < 8	too cool
8 ≤ THI < 21	sun needed for comfort
21 ≤ THI < 24	COMFORTABLE
24 ≤ THI < 26	wind needed for comfort
26 ≤ THI	too hot

3. RESEARCH METHODOLOGY

This study was carried out in a manufacturing metalworking industry located in Portugal and intends to improve thermal workplaces conditions by following a strict methodology firstly orientated for thermal environment study and then for occupants' thermal comfort sensation.
Initially the critical areas, i.e., the workstations under hot thermal environment conditions of the industrial space were identified (thermal islands). In order to collect data, 72 points of observation were defined, as shown in Figure 3.
These points of observation represent the pillars of the building around the study area, being specifically chosen to facilitate authors' orientation during measurements, since they are near to workstations.
In each point of observation, data related to air temperature T (ºC), air relative humidity U (%) and wet bulb temperature (ºC), was collected using the measuring instrument *'Testo 435-4'.*

This set of data was collected during two shifts, morning shift (10:30 am) and afternoon shift (15:00pm), every two hours (two measurements per shift), inside and outside the industrial area.

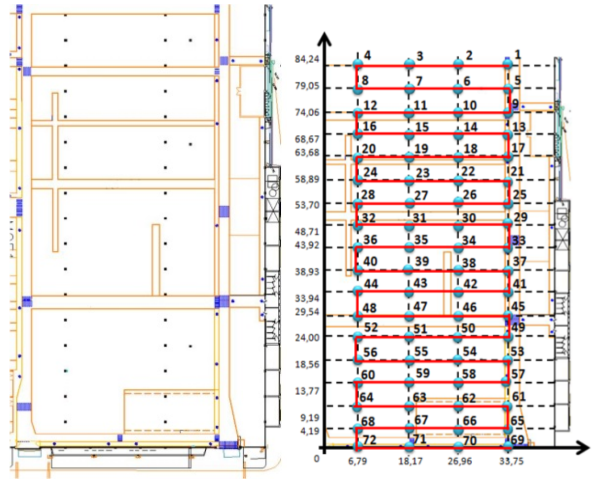

Figure 3. Layout and points of observation

During these two instants two symmetric paths were considered in order to understand the oscillations of study area thermal pattern during a short period of time (2hours approximately, as each run/path takes about 1 hour to course). To authenticate the data collected, weather charts, air temperature graphics and air relative humidity graphics were also downloaded from *Instituto Português do Mar e da Atmosfera- IPMA* (https://www.ipma.pt).
To analyse the data collected, two thermal indexes were applied: EsConTer [21] and THI [22]. These thermal indexes were chosen to perform the current study because *EsConTer* index provides an intuitive and easier interpretation of thermal comfort and THI index is commonly mentioned in vast case studies in literature.
Therefore, an algorithm in Matlab was created for the purpose of generating colour maps to identify the most vulnerable areas in the industrial space. The Matlab algorithm reads the values of the data collected by the measuring instrument (input), reproduces the mentioned indexes (processing) and in order to facilitate these two indexes interpretation, generates the colour maps (output). From the colour maps reading, five workstations were selected and considered as the most critical.
Concerning the empirical study, a survey and thermal environment data were gathered among the selected five workstations. The survey consisted in a thermal sensation colour scale (as shown in Figure 2) which was answered by the respective workers of those workstations with a tag in their thermal sensation corresponding colour. Training about survey filling was given to workers right before its application.
Indeed, these parameters were enough to apply both indexes and interpret workers thermal sensation, nevertheless ventilation conditions were also registered, as well as the amount/type of clothing worn by workers to better comprehend the results and to suggest improvement measures.

4. RESULTS AND DISCUSSIONS

The interpretation of the industrial area thermal environment was made based on colour maps, reproduced by the Matlab algorithms, as shown in Figures 4, 5, 6 and 7. These figures represent one spring measurement day, 3rd of April 2013, during the morning.

Figure 4 and 5 represent an expected and unequivocal relation between air temperature and air relative humidity, where warmer areas are also the most humid, namely around the points (5, 40), (5,75), (35,75) and (35, 40). These areas, represented by darker red, characterize the areas strongly affected by extremely hot and humid environments.

Figure 6 and 7 represent the colour maps of EsConTer and THI indexes generated with data from the previous two figures, air relative humidity and air temperature. The values obtained from THI and EsConTer indexes reveal a significant correlation coefficient (0.964), which raises the same considerations for both indices.

The zones colored by darker red are considered the thermal islands affected by hot thermal stress.

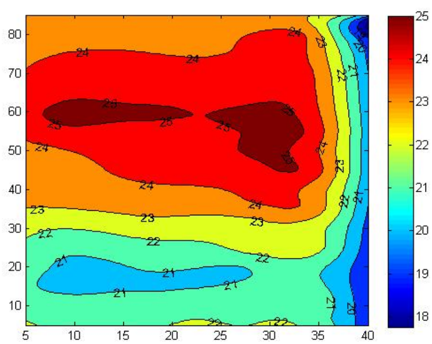

Figure 4. Air temperature pattern (ºC)

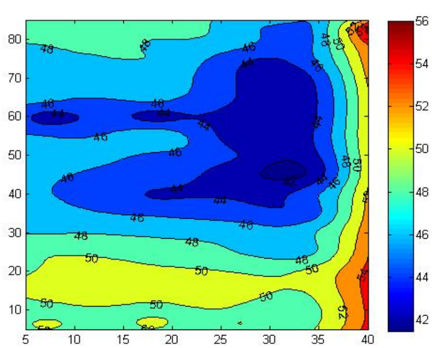

Figure 5. Air relative humidity pattern (%)

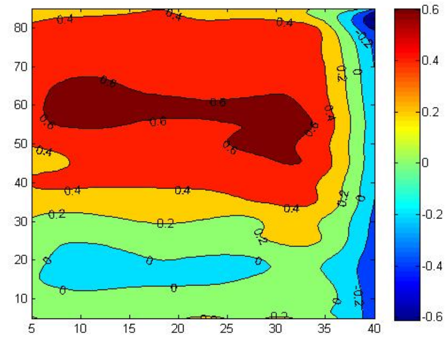

Figure 6. EsConTer thermal pattern

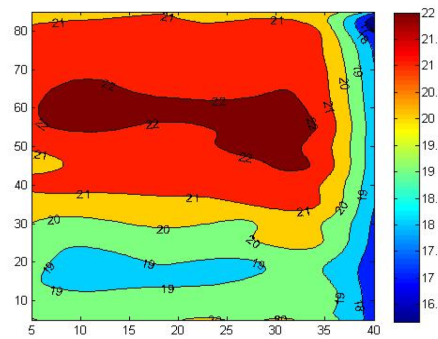

Figure 7. THI thermal pattern

To these areas, characterized as critical, a new algorithm in MatLab was applied, in order to zoom (amplify) them and find exactly the points/workstations where stress occurs, as shown in Figure 8, 9, 10 and 11.

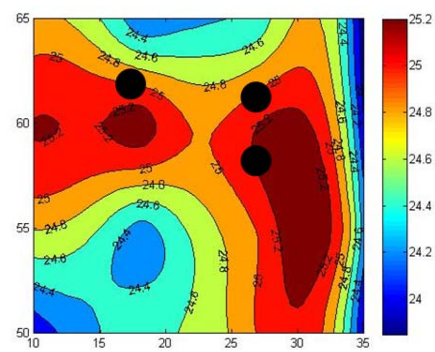

Figure 8. Air temperature and critical workstations (zoom algorithm)

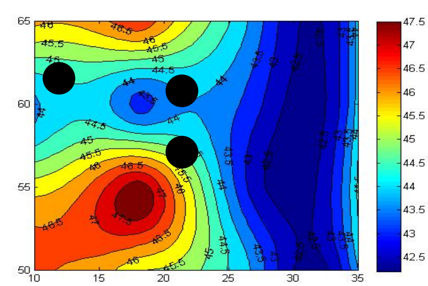

Figure 9. Relative humidity and critical workstations (zoom algorithm)

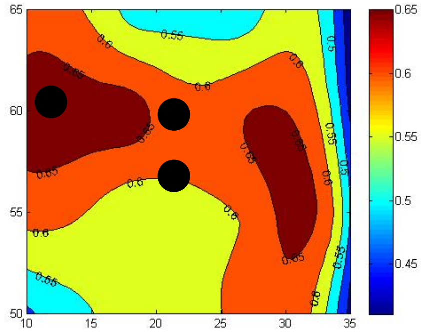

Figure 10. EsConTer and critical workstations (zoom algorithm)

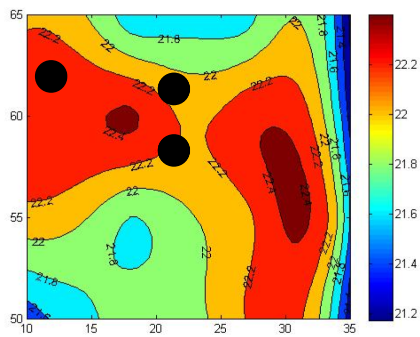

Figure 11. THI and critical workstations (zoom algorithm)

In the last four figures only three of the five selected workstations are represented with black small circles. This fact is justified regarding the limitation of the graphics' axis and stress intensity felt during the day in study, 3rd of April 2013.

Regarding Figures 8 and 9 it is possible to analyse similar information as in Figures 4 and 5, but in more detail. In these figures more thermal curves are shown, being the highest value of air temperature around 26ºC. The selected workstations do not coincide exactly with the most stressed areas because some of the areas in this company layout are free of workstations or represent some machines position, where nobody works or interacts directly with, during a long period of time. The selected workstations were the ones which represent fixed workstations, where workers spend a long period of time with.

Figure 10 and Figure 11 represent information in more detail about Figure 6 and Figure 7 respectively. Also in Figures 10 and 11 it is possible to see the correlation between both indexes.

Considering the collected workers' thermal sensation through the colour scale, the same conclusions can be taken, namely, regarding the correlation between EsConTer values and workers' thermal sensation. Regarding Figure 12, where this relation can be observed, is possible to conclude that EsConTer index may well describe workers' thermal sensation, as both variables show having an almost linear relation.

The values of the graphic do not represent a perfect linear relation, as thermal sensation collected by surveys entails subjectivity aspects, however this relation cannot be neglected.

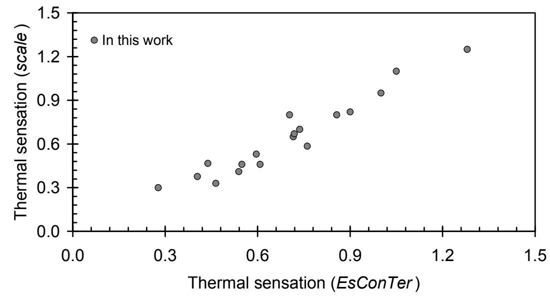

Figure 12. EsConTer and workers' thermal sensation (colour scale)

The data represented in presented figures corresponds to a day (3rd of April 2013) and a period of a day, morning, nevertheless, when remaining data was analysed, the same or similar conclusions were obtained. Nevertheless, it was possible to verify the influence of diurnal cycle in the space inner environment, i.e., the values of thermal stress increase significantly during afternoon, until about 17:00pm.. It happens because of the greenhouse effect that occurs inside of the industrial space which can be particularly felt during sunny days, when external temperatures are higher, mostly during spring and summer. During other seasons this phenomenon also occurs, because of normal sun cycle (during noon the sun is exactly halfway between sunrise and sunset, which means that appears in the highest position in the sky), and due to the energy storage in the industrial space.

During the two symmetric runs, in morning or afternoon measurement periods, no difference was observed. The data collected during first and second runs were extremely similar, showing that indoor thermal dynamic does not change significantly in a short period of time.

Regarding Figure 13, which represents workers' thermal sensation collected by surveys (colour scale) and the time of inquisition, it is possible to observe the conclusions previously taken.

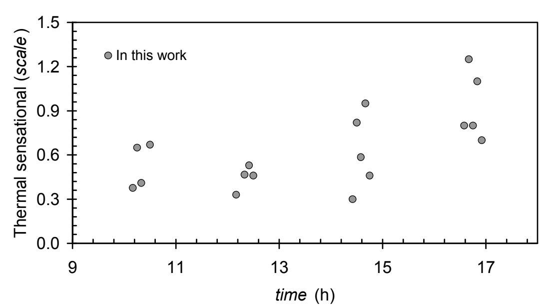

Figure 13. Thermal sensation and measurement time

In Figure 13 four instants of inquisition can be visualized, the first two during morning shift (10:00am and 12:00am) and the others during afternoon shift (around 14:00pm and 17:00pm). The highest thermal sensation values were observed in second shift (afternoon). At 17:0pm the peak of thermal sensation was observed, with values between 0.75 and 1.30 which represent hot thermal stress. Provided that it is possible to consider that in the five selected workstations, affected by those thermal conditions, workers work under thermal stress, mainly in afternoon period. The individual thermal sensation was not equal to every person in each workstation because of the subjectivity associated to this research variable and because in some measuring points a free energy source or ventilation displays were detected, bringing more comfort to workers.

As referred in methodology chapter, beyond thermal environment variables and workers' thermal sensation more data were collected. Regarding clothing insulation collected data the graphic represented in Figure 13 was obtained, comparing clothing insulation and indoor air temperature.

Figure 14, based in Liu *at al*. [7] studies, represents the clothing personal adaption to thermal environments. It is unanimous that low temperatures characterize winter season and high temperatures summer season, being the average values of clothing insulation in this typical seasons around 1,2Clo and 0,4Clo respectively [7]. In transition seasons the average clothing insulation values are around 0.8Clo in spring and 0.6Clo in autumn. The amount of values analysed in this paper was collected during spring and it is represented in this figure by green circles. The collected values have a clothing insulation resistance around 0.5Clo and 0.8Clo and around 24ºC and 26ºC, regarding indoor air temperature.

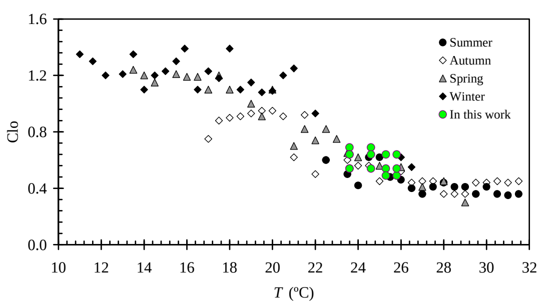

Figure 14. Clothing insolation tendencies with indoor air temperature (adopted from [7])

Considering the results obtained by Liu *at al*. [7] and those resulting from this study it is possible to confirm that both are in agreement, which allows the authors to conclude that collected data describes the industrial space thermal environment correctly.

5. CONCLUSIONS

The results of this work show an industrial thermal environment study regarding thermal indexes application, namely regarding EsConter index. The EsConTer index had shown itself capable to describe the thermal environment of an industrial space due to its correlation with THI and at the same time adequate to define workers' thermal sensation.

Additionally, the different colour maps which had generated thermal patterns seemed useful and intuitive to demystify the most vulnerable areas. Thermal colour scale used to indicate workers' thermal sensation proved to be useful and more intuitive than ASHRAE seven-points scale to study personal thermal feelings and to identify thermal stress.

These results allowed the identification of the areas under thermal stress in an industrial company and provided very useful knowledge for Health and safety department.

Moreover, the authors believe that a better work environment can lead to better performance results and increase workers' productivity, as comfort at work is the source for work motivation and work dynamic.

6. REFERENCE

[1] Emmanuel, R. (2005), *"Thermal comfort implications of urbanization in a warm-humid city: the Colombo Metropolitan Region (CMR), Sri Lanka"*, Building and Environment, 40, 1591–1601. doi:10.1016/j.buildenv.2004.12.004.

[2] Felix, V. B., Moura, D., Pereira, M. L., & Tribess, A. (2010), *"Evaluation of thermal comfort in surgical environments using Fanger's method and equivalent temperatures",* Ambiente Construído, 10, 69–78.

[3] Pinto, A. M. P. (2009), *"Análise ergonómica dos postos de trabalho com equipamentos dotados de visor em centros de saúde da administração regional de saúde do centro.",*Universidade de Coimbra. (in portuguese).

[4] ASHRAE (2001). *Thermal Comfort*. American Society of Heating, Refrigerating and Air-Conditioning Engineers, 2001 ASHRAE HandbookCD. Englewood, Colorado 80112-5776 USA, Chapter 8: 1-29.

[5] Meles, B. A. (2012), *"Ergonomia Industrial e Conforto Térmico em postos de trabalho",* Universidade de Aveiro.

[6] Castilla. M., Álvarez. J.D., Berenguel. M., Rodríguez. F., Guzmán. J.L., Pérez. M., (2011). A comparison of thermal comfort predictive control strategies, Energy and Buildings, 43(10), 2737-2746.

[7] Liu, J., Yao, R., Wang, J., Li, B. (2012). Occupants' behavioural adaptation in workplaces with non-central heating and cooling systems. Applied Thermal Engineering. 35, 40-54.

[8] Daum, D., Haldi, F., Morel, N. (2011). A personalized measure of thermal comfort for building controls. Building and Environment. 46, 3-11.

[9] Bluyssen, P. M., Aries, M., & van Dommelen, P. (2011), *"Comfort of workers in office buildings: The European HOPE project",* Building and Environment, 46(1), 280–288. doi:10.1016/j.buildenv.2010.07.024.

[10] Pereira, D. (2013), *"Climatic process and their effects on thermal dissipation in classrooms at public schools",* In Sho'13-International Symposium on Occupational Safety and hygiene. Guimarães, Portugal.

[11] Zhang, H., Arens, E., Kim, D., Buchberger, E., Bauman, F., & Huizenga, C. (2010), *"Comfort, perceived air quality, and work performance in a low-power task–ambient conditioning system"*, Building and Environment, 45(1), 29–39. doi:10.1016/j.buildenv.2009.02.016.

[12] Pinheiro, I. P. T. (2011), *"Conforto Térmico e Bem-Estar numa Superfície Comercial Isolada",* Universidade do Porto. (in portuguese).

[13] Rodrigues, F. A. G. (2007). Conforto e Stress Térmico: uma Avaliação em Ambiente Laboral. Universidade de Aveiro. Porto (in portuguese).

[14] Fanger, P. (1972). Thermal Comfort. McGraw-Hill (2nd ed): New-York.

[15] ASHRAE 55 (2004). Thermal environmental conditions for human occupancy. American Society of Heating, Refrigerating and Air-Conditioning Engineers – ISBN/ISSN: 1041-2336.

[16] ISO 7730 (2005*). Ergonomie des ambiances thermiques — Détermination analytique et interprétation du confort thermique par le calcul des indices PMV et PPD et par des critères de confort thermique local*. Switzerland, International Standardisation Organisation, Geneva, Suisse.

[17] Costa, E., Baptista, J., Diogo, M.,Magalhães, A. (2011), *"Hot Thermal Environment and its impact in productivity and* accidents", In SHO 2011-International Symposium on Occupational Safety and hygiene. Minho, Portugal.

[18] Yao, R., Li, B., & Liu, J. (2009). A theoretical adaptive model of thermal comfort – Adaptive Predicted Mean Vote (aPMV). Building and Environment, 44(10), 2089–2096. doi:10.1016/j.buildenv.2009.02.014.

[19] Djongyang, N., Tchinda, R., & Njomo, D. (2010). Thermal comfort: A review paper. Renewable and Sustainable Energy Reviews, 14(9), 2626–2640. doi:10.1016/j.rser.2010.07.040.

[20] Liang, J., & Du, R. (2005). Thermal Comfort Contrl Based on Neutral Network of HVAC Application. In 2005 IEE Conference on Control Applications. Toronto, Canada.

[21] Talaia, M. & Simões, H. (2009). Índices PMV e PPD na Definição da "performance" de um Ambiente. Livro de atas do V Encontro Nacional de Riscos e I Congresso Internacional de Riscos, Coimbra, de 29 a 31 de Maio. Porto (in portuguese).

[22] ASHRAE 55 (2004). *Thermal environmental conditions for human occupancy*. American Society of Heating, Refrigerating and Air-Conditioning Engineers – ISBN/ISSN: 1041-2336.

[23] Thom, E.C. (1959). The Discomfort Index, Weatherwise: 57-60.

[24] Nieuwolt, S. (1977). Tropical climatology. London: Wiley.

[25] Talaia, M., Meles, B. & Teixeira, L. (2013). Evaluation of the Thermal Comfort in Workplaces – a Study in the Metalworking Industry. Occupational Safety and Hygiene. Editors Arezes et al. Taylor & Francis Group, London, 473-477.

Stvaranje produktivnih radnika u industrijskom kontekstu iz definicije toplotnog komfora

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Apstrakt

O ljudskom delovanju među problemima zaštite životne sredine i razvoja državapisalo je nekoliko autora. Toplotni komfor je izuzetno širok koncept koji je direktno povezan sa ergonomijom, energetskom potrošnjom zgrada i performansama radnika. Ovaj rad ima nameru da analizira toplotno okruženje unutar jedne portugalske industrije za proizvodnju metalnih delova kako bi se razumeo uticaj na performanse i dobrobit radnika. Za ove potrebe, izvršene su dve vrste studija: analitička i empirijska. Analitičko istraživanje je posmatralo studiju unutrašnjeg toplotnog okruženja vezano za dva toplotna indeksa: EsConTer i THI. Empirijsko istraživanje se sastoji od studije topotnog osećaja radnika, vezano za skalu toplotnih boja zasnovanu na ASHRAE skali od sedam toplotnih tačaka. Stoga, merni instrument, Testo 435-4, je korišćen kako bi se prikupili podaci o temperaturi vazduha (ºC), relativnoj vlažnosti vazduha (%) i temperaturi vlažne kugle termometra (ºC). EsConTer indeks je bio najiznenađujući primenjeni metod jer je pokazao da je sam sposoban da opiše toplotno okruženje industrijskog prostora zbog svoje korelacije sa THI, a u isto vreme je adekvatan za definisanje toplotnog osećaja radnika. Štaviše, autori smatraju da su studije toplotnog okruženja na radnim mestima značajan aspekat za poboljšanje produktivnosti radnika u poslovnom kontekstu.

Ključne reči: *ergonomija,toplotni komfor, toplotni osećaj, radno okruženje, radnici*