



A new simplified model for evaluating thermal environment and thermal sensation: An approach to avoid occupational disorders



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ABSTRACT

Thermal heat stress is a cause of many occupational disorders that disrupt worker performance and the quality of work and, in extreme cases, can lead to death. In the industrial context, thermal discomfort is cited as one of the major causes of dissatisfaction in workplaces when people are exposed to extremely hot or cold thermal environments. Given the time that people spend in their workplaces, studies evaluating the comfort of the thermal environment are becoming increasingly important. However, comfort evaluation studies are time-consuming and for many organizations become expensive and difficult to implement due to the lack of a simplified model for evaluating the thermal environment of workplaces and the thermal sensations of their occupants.

This paper aims to show the possibility of assessing the thermal patterns of industrial spaces and consequently identifying the most critical areas in terms of thermal comfort, using thermal indexes supported by real data collected using inexpensive measuring tools. This study was carried out in two Portuguese industrial manufacturing facilities with different characteristics, evaluating the thermal environment and the workers' thermal sensation in the season of spring. The data related to environmental parameters were collected using two similar measuring instruments, *Testo 435-4* and *Center 317-temperature humidity meter*, while the workers' thermal sensations were collected using a thermal sensation colour scale that is aligned with the ASHRAE seven-point thermal sensation scale. The results were reproduced in colour maps based on MatLab algorithms, using the calculation formula of three thermal indexes, EsConTer (a new index), THI, and PPD.

The applied methodology, using the EsConTer index, proved to be an interesting method for easily studying thermal environments and predicting the thermal comfort of an indoor space. Moreover, the representation of thermal indexes in colour maps is an informative approach, prompting recommendations and development actions with the aim of providing more comfortable, safer, and healthier work conditions, and minimizing occupational disorders. Indeed, the practical results were appreciated by the Health and Safety Department of each industry in order to develop measures that improve the occupational health of the occupants to prevent work accidents and work-related disorders.

Accordingly, the methodology applied in this work, using a colour scale with the EsConTer index, proposes a new, simplified model for thermal stress risk evaluation, aiming to minimize difficult and time-consuming investigations to identify thermal comfort problems in workplaces. The coloured maps generated by MatLab algorithms proved to be a useful tool to visualize the thermal pattern of an environment, and consequently to identify thermal comfort problems.

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1. Introduction

The work environment is defined as a set of surrounding elements which influences the workers' tasks at their workstations. Ergonomics is the scientific discipline that studies workplaces in

order to adapt workstations to workers' welfare needs. It aims to understand the interactions and the relationship between the workers and their work environment, and create workstations with the required conditions to achieve high performance and prevent work-related disorders (Guimarães et al., 2015; IEA, 2014; Wisner, 1992).

Work-related disorders, also known as occupational diseases, are unexpected and unplanned occurrences which arise in connection with work, leading to personal injury, disease, or death (Zhou et al., 2014). These disorders may be divided into different categories, such as mental disorders, noise-induced hearing loss, respiratory diseases, cardiovascular diseases, infectious and parasitic diseases, and musculoskeletal disorders (MSDs). Roman-liu (2013) states that a wide range of external factors in the work environment cause musculoskeletal disorders, one of the most widespread occupational pathologies (Chiasson et al., 2012; Zare et al., 2015). MSDs are developed when work demands exceed the worker's ability, i.e., the cumulative effect to the worker when under protracted load work, such as repetitive motion, excessive force, awkward or sustained postures, or prolonged sitting and standing (Ogg, 2011; Roman-liu, 2013; Costa and Vieira, 2010). These types of disorders are, citing Costa and Vieira (Costa and Vieira, 2010), associated with injuries or dysfunctions affecting muscles, bones, nerves, tendons, ligaments, joints, cartilages, and spinal discs.

There are several studies that demonstrate a strong relationship between comfort, health, environment control in indoor spaces, and productivity in workplaces (Akimoto et al., 2010; Bluysen et al., 2011; Escorpizo, 2008; Lan et al., 2011; Mohamed and Srinavin, 2002; Wagner et al., 2007). One of the crucial human requirements is a working environment that allows people to perform their work optimally under comfortable conditions (Lan et al., 2011). Furthermore, citing Huizenga et al. (2006), the major cause of dissatisfaction in workplaces is thermal discomfort.

Thermal discomfort, also termed thermal stress, corresponds to a dissatisfied state on the part of a person in terms of their thermal sensation, when exposed to extremely hot or cold thermal environments (ASHRAE 55, 2010; Teixeira et al., 2014). Thermal discomfort may be felt all over or in a particular part of the body (ASHRAE, 2001; Bluysen et al., 2011; Yigit et al., 2015). This thermal state may reduce productive capacity or cognitive and physical performance, increasing the likelihood of fatigue and injury to workers and workplace accidents (ASHRAE, 2001; Bröde et al., 2013; Jackson and Rosenberg, 2010; Riniolo and Schmidt, 2006). Thus, extreme thermal stress is related to many work-related diseases associated with all categories of occupational disease, for example skin lesions, heat stroke, hyperthermia, heat exhaustion, heat cramps, heat syncope, heat rash, and human body collapse (ASHRAE, 2001; Jackson and Rosenberg, 2010).

According to Cox (2005) a healthy environment can be found when the combined physical, chemical, and biological properties do not cause or aggravate any of the workers' diseases, ensuring high levels of comfort and contributing to the best performance in executing their functions or tasks.

In this context, the scientific literature shows that research on the thermal environment in workstations is necessary, as individuals spend most of their time at work (Felix et al., 2010; Wisner, 1992). Thus, an understanding of the adaptation of individuals to the workstation and their reaction to different thermal environments is very important (Emmanuel, 2005). Furthermore, most of the studies in the scientific literature analyse work environments using thermal indexes, such as Wet-Bulb Globe Temperature (WBGT) (ISO 7243, 1989), Equivalent Temperature (ET) (Matzarakis et al., 1999), Relative Strain Index (RSI) (Lee and Henschel, 1963), Temperature-Humidity Index (THI) (Nieuwolt,

1977), Predicted Mean Vote (PMV), and Predicted Percentage Dissatisfied (PPD) (ISO 7730, 2006). PMV and PPD are examples of indexes which take into consideration the individual's thermal sensation, which would seem to suggest a better approach to a given thermal environment. However, according to the methodology applied in most case-studies reported in the literature, it is difficult to understand the thermal patterns of an indoor space using cheap and easy measuring tools which also take into account the thermal sensation of its occupants. In fact, the subjectivity associated with the thermal sensation concept hinders an objective analysis of thermal comfort that allows the creation of indoor spaces which satisfy most of the population who occupy them (Arezes et al., 2013; Bröde et al., 2013; De Giuli et al., 2014; Oliveira et al., 2014).

It should be noted that the study of the thermal environment, instigated by Fanger (1972) and associated with ergonomics, is mainly considered as a corrective and reactive intervention because it is usually applied to existing situations.

This paper aims to show the possibility of ascertaining the thermal patterns of industrial spaces and consequently identifying the most critical areas in terms of thermal comfort using thermal indexes supported by real data collected using inexpensive measuring tools. This study was carried out in two Portuguese industrial manufacturing facilities with different characteristics, evaluating the thermal environment and the workers' thermal sensation in the season of spring. The results were reproduced in colour maps based on MatLab algorithms, using the calculation formulas of three different thermal indexes – EsConTer, THI, and PPD.

2. Material and methods

The present study was carried out in two Portuguese manufacturing industries with different characteristics, but both associated with heat thermal stress. The first industry (designated by IND_1) is a metalworking company that belongs to a giant German group with many companies all over the world. The second industry (designated by IND_2) is a family business associated with traditional glass production in *Marinha Grande*. In this section the methodology used in the present work will be briefly described, explaining the procedures followed to collect data, analyse information, and interpret the results.

2.1. Measurement of environmental parameters

This study comprised measurements of environmental parameters and investigation of workers' subjective sensations in two different industrial facilities in spring.

Firstly, in order to gather indoor environmental parameters, the layouts of both interior spaces were analysed with the purpose of identifying the observation points which were to be used to collect data. Fig. 1 presents the layout of the studied areas and the respective points of observation selected for IND_1 (on the left) and for IND_2 (on the right). These areas were selected according to the recommendations of the directors of the respective companies. In the layout, the x and y axes represent the dimensions of the study areas in metres (m), and the numbered circles represent the places where the measurement was made (i.e. the points of observation) in each case-study. As can be seen in Fig. 1, in IND_1 seventy-four points of observation were identified, seventy-two (from 1 to 72: blue circles) inside the study area, and two (73 and 74: grey circles) outside the study area; in IND_2 forty points of observation were identified, thirty-six inside the study area (from 1 to 36: blue circles) and four outside the study area (from 37 to 40: grey discs). The measurements outside of the study area were required because the

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