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Chapter

Ergonomic Evaluation of Thermal Stress in a Tunisian Steel Industry

Amira Omrane, Taoufik Khalfallah and Lamia Bouzgarrou

Abstract

This work aims to assess thermal stress based on the various measurable thermal stress parameters (wet bulb temperature, air speed, radiation temperature, black globe temperature...). A cross-sectional study was carried in a steel company. The evaluation of thermal stress was made by physical parameters measurment (air temperature, relative humidity, air velocity, globe temperature, clothing insulation, metabolism of work) and analyzed according to the International Standard Organization (ISO) 7933 "Analytical determination and interpretation of heat stress using calculation of the predicted heat strain". Eighty male workers were mean ageed of 37.9 ± 9.25 years. The climatic conditions category was three (meaning a Long-term stress) in 68.18% of the workers and four (Short-term stress meaning the occurrence of health problems within 30 to 120 minutes of exposure) in 30.3% of workers. The long and short-term thermal stress identified in this study spearhead a prevention strategy (automation of manufacturing processes, improvement of the organization of tasks, and the strengthening of medical surveillance of workers).

Keywords: ergonomics, thermal stress, steel industry, international standard organisation, prevention

1. Introduction

Historically, the arduous sectors of work described have been physically heavy such as work in the steel industry. In this context, this arduousness is related to significant thermal constraints caused by the production processes. In Tunisia, this sector employs more than 2498 workers [1]. Currently, the available tools for quantifying strain and thermal stresses are the result of a great research at the origin of European directive 89/654/EEC and of 14 standards developed by the International Standard Organization (ISO) [1–3]. This large number of thermal stress assessment tools reflect the complexity of prediction models and the difficulties in defining a simple model that can be used in various work situations [2]. This work was encouraged by the importance of the thermal constraints in the steel sector, the characteristics of the climate in Tunisia especially in the hot season and the employability of this sector. This research was conducted in the governorate of Monastir. It has a dry mediterranean climate with hot summers, extremely mild winters, much sunshine and low rainfall year-round. The city sits in the northeast of Tunisia, on its central coast. The average high temperature of 29°C (84°F) in June

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skips past the 30°C (86°F) mark in the middle of the month and rises to 33°C (91°F) in July and August.

This work aims to assess thermal stress based on the various measurable thermal stress parameters (wet bulb temperature, air speed, radiation temperature, black globe temperature...).

2. Materials and methods

This is an exhaustive cross-sectional study carried out during the two months of August and September 2015, in a Tunisian steel company specialized in the manufacture of springs for heavy vehicles and located in the industrial zone of Teboulba-Moknine of the governorate of Monastir, Tunisia. This company counted 120 workers. A list of names and contact details of all workers was provided by the Human Resources Management Department. Included patients were those who had a job tenure exceeding one year and belonged to production workshops. Exclusion criteria consisted of a participation refusal and a disability or cognitive impairment precluding participation.

The survey was preceded by an individual interview with each eligible worker in order to explain the objectives of the work, its practical progress, guarantee anonymity and obtain informed consent. During the survey, data collection focused on general characteristics, as well as thermal stress measurements. Data analysis was subsequently carried out by the same investigator, using statistical and computer programs.

2.1 Data collection

1. General characteristics related to age, weight, height, Body Mass Index (BMI)...

2. Measurement of the thermal environment carried out in the workstation of each worker and in the external environment (rest area during recovery breaks). These recordings were preceded by open observation days to estimate the actual duration of the activity set at five hours. Open observation also enabled a contact with the operators and the collection of their opinions concerning the time and extent of the temperature peak. The thermal stress mainly concerns the morning and afternoon shiftwork and extended from 7 am to 7 pm. Thus, measurements were made every 15 minutes at the workstations. The values obtained were means of all measurements performed. These measurements were carried out in accordance with the ISO 7726 standard "*Ergonomics of the thermal environment - Instruments for measuring physical quantities*" [4] using:

    - a thermo-hygrometer (TA5 Thermal Anemometers) placed at the workstation at a height of 1.5 m, far from the employees and sheltering the sensor against radiation (sun, oven, etc.). It is a calibrated device with a low response time, a stabilization time of a few seconds enabling punctual measurement of air temperature and relative humidity.

    - a vane anemometer (YK-80AP Vane Anemometer) for measuring air speed. The measurement was discontinuous and the axis of rotation was placed in the direction of the air flow.

- a black globe thermometer (Black globe TP_875.1/TP_876.1) placed at the work station at a height of 1.5 m, keeping the employees apart. The measurement time is about 20 min.

2.2 Thermal stress analysis

This evaluation was conducted by the program "Ergonomics of work in heat - Calculation of PMV indices - PPD, WBGT and P.H.S." developed by Prof. Malchaire [5] and based on the various physical parameters of the thermal environment (air temperature, black globe temperature, relative humidity, speed of air) as well as on:

- The equivalent metabolism M estimated based on the ISO 8996 standard "Ergonomics of the thermal environment - Determination of energy metabolism" [6].

- Iclo clothing insulation assessed in accordance with the ISO 9920 standard "Ergonomics of the thermal environment - Determination of thermal insulation and resistance to evaporation of a clothing" [7] Thus, the program identifies the parameters:

    - Predicted Mean Vote (PMV) at work and during recovery. This PMV index predicts the average vote value of a large group of people on the following seven-point thermal sensation scale: + 3 very hot; + 2 hot; + 1 slightly hot; 0 neither hot nor cold; −1 slightly cold; −2 cold; −3 very cold [1]

    - Predicted Percentage of Dissatisfied (PPD) in the workplace and during recovery. This PPD index is defined as the percentage of people who, placed in identical conditions, consider themselves cold/very cold or hot/very hot. These are the people who would have cast a vote outside the interval (−1, 1) on the sensation scale [1]. To obtain a thermal comfort situation, it is recommended that the PPD be less than 10%, which corresponds to a PMV between −0.5 and + 0.5 [1].

    - Thermal sensation in work situation and during recovery: This index is calculated from the PMV and PPD indices and In accordance with ISO 7730 "Ergonomics of the thermal environments - Analytical determination and interpretation of thermal comfort by calculating the PMV and PPD indices and by local thermal comfort criteria" [8].

    - The natural humid temperature (Thn) in work situation and during recovery.

    - The Wet Bulb Globe Temperature (WBGT) in the workplace and during recovery. The WBGT corresponds to a weighting between the radiation temperature and the natural wet bulb temperature.

$$\begin{aligned} \text{WBGT} &= 0.7\ \text{thn} + 0.3\ \text{tg without solar R} \\ &= 0.7\ \text{thn} + 0.2\ \text{tg} + 0.1\ \text{ta with solar R} \end{aligned} \tag{1}$$

    - The WBGT limits in work situation and during recovery

The working hours - rest limits (K): This duration is calculated in accordance with ISO 7243 "Hot environments - Estimation of the thermal stress of man at work, based on the WBGT index (wet bulb and black globe temperature)" [9] and according to the following equation:

$$K = \frac{32 - WBGT}{32 - WBGT_{lim}} \tag{2}$$

- Sweat flow in a work situation and during recovery.
- Total water loss in the workplace and during recovery
- The time interval indicated for drinking 200 cc of water at 10°C
- The core temperature reached after 8 hours of work
- The time interval to achieve excessive water loss
- The time interval to reach a core temperature of 38°C.
- The climatic condition categories in the work situation and during recovery: Identified in five levels in accordance with ISO 7933 "Analytical determination and interpretation of heat stress using calculation of the predicted heat strain" [10]:

    a. C1: Comfort category: neither discomfort nor health risk;

    b. C2: Discomfort category: discomfort that can be very significant, but without health risk;

    c. C3: Category of long-term constraint: discomfort and risk of dehydration after several hours of exposure;

    d. C4: Short-term stress category: health risk after 30 to 120 minutes of exposure;

    e. C5: Immediate Constraint Category: health risk even for very short exposure (less than 30 minutes)

3. Results

3.1 Study population

The survey was carried out exhaustively among the operators of the production workshops of the steel company, and included a total of 80 male workers. The mean age was 37.9 ± 9.25 years and the mean professional tenure was 12.5 ± 11.4 years (**Table 1**).

3.2 Evaluation of thermal stress

This stress was evaluated based on the different physical parameters of the thermal environment (air temperature, temperature of the black globe, relative

Characteristics	
Men	80
Mean age ± (extremes)	37,9 ± 9,25 years (from 21 to 54 years)
Groups: n(%) • **Men > 45 years:** • **Men < 45 years:**	62 (77,5%) 18 (12,5%)
Married Depending children: • 0 **child** • 1 **to** 3 **children** • ≥3 **children**	61 (76,25%) 10 (12,5%) 27 (33,75%) 24 (30%)
Mean job tenure ± (extremes)	12,5 ± 11,4 years (from1 to 35 years).
Mean BMI ± (extremes) • **Normal** • **Overweight** • **Obesity**	26,9 ± 3,6 kg/m^2 (17,8 à 38,7 kg/m2) 19 (23.75%) 49 (61,25%) 12(15%).

Table 1.
Study population.

humidity, and air speed) as well as on the equivalent metabolism M and the Iclo clothing insulation index evaluated in accordance with the ISO 9920 standard "Ergonomics of the thermal environment - Determination of thermal insulation and resistance to evaporation of a clothing" [7].

1. *Thermal environment*: The mean air temperature inside the workshops was 29.66 ± 2.57°C with a mean air speed of 0.58 ± 0.82 m/s, a mean relative humidity of 59, 56 ± 10.98 and a mean global temperature of 34.15 ± 2.87°C (**Table 2**).

2. *Thermal stress evalation*: Based on the evaluation of the equivalent metabolism and the characteristics of the thermal environment, the thermal stress to which the workers of the different production workshops were exposed, was evaluated by the indices of Predicted Mean Vote (PMV) and Predicted Percentage of Dissatisfied (PPD) as follows (**Table 3**):

    - Mean PMV of 3.2 ± 0.47 with extremes ranging from 1.5 to 4.7.
    - Mean PPD 97.3 ± 3.7% with extremes of 50 to 100%.

    Thereby:

    - The Thermal sensation was rated "very hot" on 98.75% of all working days.
    - The mean WBGT was 27.5 ± 2.62°C
    - The mean WBGT limit 28.4 ± 0.81°C. Based on previous estimates, and in accordance with ISO 7243 "Hot environments - Estimation of the thermal stress of humans at work, based on the WBGT index (wet bulb and black globe temperature)" [9], the mean cut-off working time was evaluated at 48 ± 13.19 min.

	In door	Out door
Mean air temperature (Ta) (°C)	29,66 ± 2,57	27,99 ± 1,87
Mean air speed (Va) (m/s)	0,58 ± 0,82	0,23 ± 0,26
Mean relative humidity (RH) (%)	59,56 ± 10,98	68, 56 ± 7,78
Mean Globe temperature (Tg) (°C)	34, 15 ± 2,87	40,21 ± 7,95

Table 2.
Physical parameters of thermal stress.

	Minimum	Maximum	Mean	Standard deviation
PMV	1,5	4,7	3,2	0,47
PPD (%)	50	100	97,3	3,7
WBGT (°C)	20	29,9	27,5	2,62
Limit WBGT (°C)	26,5	30,2	28,4	0,81
Work limit time/60 min (min)	3	60	48	13,19
Sweat loss (g/h)	230	1130	699,4	160,03
Total water loss (g)	1780	10600	6083,7	1737,3
Time interval Indicated to drink 200 cc of water at 10 °C (min)	10	55	19,4	5,49
Central temperature after 8 hours of work (°C)	37,3	42	38,6	1,03
Time to reach excessive water loss (min)	160	480	292,6	74,64
The central temperature reaches 38°C at the end of (min)	46	385	131,3	60,89

Table 3.
Thermal stress evaluation.

In addition, the mean sweat flow was 699.4 ± 160.02 g/h and the mean total water loss was estimated to be 6083.7 ± 1737.29 g.

In accordance with the recommendations of ISO 7933 "Analytical determination and interpretation of thermal stress based on the calculation of the foreseeable thermal strain", it would be imperative to offer all workers oral rehydration by water at 10°C after a calculated average working time of 19.4 ± 5.49 min.

According to these estimates, after 8 hours of work, the average core temperature would reach 38.6 ± 1.03°C. Excessive water loss was reported among 80.3% of workers and would be reached after 292.6 ± 74.64 min. The core temperature would be 38°C, based on these evaluations, among 51.5% of workers who received a heart rate recording after 131.3 ± 60.89 min.

In total, on the basis of these results of the estimation of thermal stresses, 68.18% of subjects would be concerned by a category 3 of climatic condition, namely "Long-term stress: discomfort and risk of dehydration after several hours of exposure" and 30. 3% of them by a category 4 of climatic condition equivalent to a "Short-term constraint: risk to health after 30 to 120 minutes of exposure".

4. Discussion

This study included measurements of the physical parameters of thermal stress followed by an evaluation of thermal stress. Informed consent from workers was obtained before the start of the study. The questionnaire survey enabled the identification of the main socio-demographic characteristics. In this study, thermal stress was evaluated by the PHS ISO 7933 index "Analytical determination and interpretation of heat stress using calculation of the predicted heat strain" [10]. The physical parameters used to calculate this index come from measurements of the environment as well as from the estimation of the equivalent metabolism in accordance with the ISO 8996 "Ergonomics of the thermal environment - Determination of energy metabolism".

The ISO 7933 standard provides a main advantage of the PHS model related to the reorganization of work, by interposing of short periods of rest during work and the distribution of drinks so as to compensate the water losses taking into account the interindividual differences in physiological responses to heat [1]. This model has been validated using data from 672 laboratory experiments and 237 field experiments [1, 11–13].

Thermal comfort is defined as a state of satisfaction against a person's thermal environment evaluated by six primary parameters providing this comfort [1]. This comfort was estimated by the PMV and PPD indices described by the ISO 7730 standard [8]. The results of this study were convincing, more than a half (65 operators) were not in a situation of thermal comfort.

It should be noted that the thermal stress is also estimated using the WBGT index described by the ISO 7243 standard [9]. This index has a fairly limited field of application, in particular while evaluating thermal stress during very short periods or conditions close to the thermal comfort [1]. The PHS model seems to be more discriminating than the WBGT index in defining the severity of thermal stress during work situation and organizing work in order to minimize or eliminate thermal stress. Metabolism value estimated for the calculation of this index comes from the results of the recording of the heart rate which gives it an accuracy of the order of ±10% and then an accurate estimation [14]. Therefore, only results of the PSH evaluation will be discussed in this work.

The climatic conditions category was 3 in 68.18% of subjects (Long-term constraint: discomfort and risk of dehydration after several hours of exposure) and 4 (Short-term constraint: health risk after 30 to 120 minutes of exposure) in 30.3% of workers. The use of this index enabled the assessment of the thermal stress and the management of work in heat [15]. Thus, workers were advised to drink water at 10° C after an average working time of 19.4 ± 5.49 min. A possible alternative is to let employees spontaneously choose their space of work or to allow them to stop working as soon as they feel some symptoms of strain [1, 16].

In this study population, the core temperature could reach 38°C after an average working time of 131.3 ± 60.89 min. The World Health Organization (WHO) Technical Report No. 412 published in 1969 stated that: "*It is not recommended that the core body temperature exceeds 38°C for prolonged daily exposure to heavy work…*" [4]. It should be emphasized that, at a rectal temperature of 38°C, an employee does not run any health risk. This limit value concerns the "average" subject and is intended to protect employees who, due to a greater intolerance to heat, evolve to higher temperatures, under the same conditions [1].

In this study, more than half of workers (58.75%) know nothing about the risks associated with working in the heat, while 10 employees have already had accidents due to heat (cramps, faintness, stroke. heat). Employees should be informed and trained to recognize signs of thermal stress and prevent the occurrence of these accidents [1, 17].

This study has limitations that warrant mentioning. The thermal stress evaluation was made by physical objective measurements that did not take into account operators' differences. Moreover, the investigation was limited to one company located in the central-eastern region of Tunisia. Therefore, findings cannot be extended to all of Tunisian companies, especially with the huge differences in weather, in characteristics and resources between sectors of activity, between industrial process and between operators.

5. Conclusion

In the light of our results and the literature data, several measures should be implemented in this steel company, to prevent both short-term and long-term effects linked to thermal stress in this environment.

Globally, the preventive approach in this sector must combine technical, organizational and medical actions. Its implementation must be multidisciplinary, involving, on the basis of the action plan proposed by the occupational physician, all of the experts involved in the development of work processes, the layout and design of workstations, such as production engineers, quality engineers, industrial hygienists, ergonomist, architects, but also the expert in the work situation; the operator himself.

Finally, additional study of thermal stress taking into account dependencies and synergistic factors and operators' differences should be performed.

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