IDENTIFICATION OF THERMAL ENVIRONMENT IN WORKPLACES PRODUCING ADVANCED SUSPENSION SYSTEMS FOR THE COMMERCIAL VEHICLE INDUSTRY AND METHODS TO NORMALIZE WORKING CONDITIONS

MARIUS KOVACS[1], ALEXANDRU FLORIN SIMION[2]

Abstract: The thermal comfort of workers depends on the balance of heat within the human body. This balance is affected by various factors in the workplace, including relative humidity, air temperature, average radiant temperature, air velocity, and clothing, as well as physical activity. The thermal sensation of the entire body can be estimated by calculating the PMV (predicted mean vote) and PPD (predicted percentage of dissatisfied) indices. The purpose of the case study was to assess the thermal environments of 14 workplaces that perform hot processing of subassemblies necessary for industrial vehicles. During the tests, a series of long-lasting measurements were carried out and the thermal sensation of the workers was calculated for each workplace. The main objective of the work is to assess the degree of comfort at workplaces performing hot metal processing and identify measures to normalize working conditions. The study results indicate in almost all cases high values of the percentage of people possibly dissatisfied with the work environment from hot processing of subassemblies necessary for industrial vehicles. Also, for these workplaces, certain measures are recommended to normalize working conditions, namely: improving ventilation installations for each work area.

Keywords: microclimate in the workplace, vehicle industry, thermal comfort

1. GENERAL INFORMATION: Presentation of the hot processing activity of the subassemblies necessary for industrial vehicles.

This paper is based on thermal sensation measurements for workers working in a company that performs hot metal processing and is organized on two successive

[1] *Ph.D. Eng., National Institute for Research and Development in Mine Safety and Protection to Explosion – INSEMEX Petroşani, marius.kovacs@insemex.ro*
[2] *Ph.D. Eng., INSEMEX Petroşani*

technological lines, namely Preparation and Assembly, comprising the following stages:

- the semi-finished steel product is first quality-checked and then cut in the cutting workshop;
- the hot processing workshop performs the following operations:
  - central bolt hole stamping and clamp hole stamping;
  - cutting out the ends and stamping holes for spacers;
  - rolling pieces at both ends, one end being cut out and ironed;
  - quenching in an oil bath in kilns at a maximum temperature of 1000 ^{o}C, followed by a return to temperatures between 400 and 800 ^{o}C in the return tunnel and finally cooling the sheets (bringing the sheets to a temperature of approx. 80 ^{o}C) in industrial water recirculated and decanted after each use cycle;
- the assembly and finishing workshop performs the following technological operations:
  - boring, milling and drilling;
  - hardening – induction of compression stresses in the surface of the metal part through controlled sandblasting. This treatment increases the aging and stress resistance of the parts and also increases the life of the parts.

Table 1. **Existing installations and machines in the company:**

Installations:	**Equipments:**
Bending - hardened installation	Mechanical presses
Bending - hardened installation	Hydraulic sockets
Bending installation	Mechanical presses
Laminor	Hidraulice Sockets
Laminor	Calibrated sockets Press to straighten
Laminating machine	The bushing press
Strain hardening plants	Mechanical saw
Press oven	Circular saw
Paint plant	Milling
Paint line	Grinder
Water cooling installation	Pneumatic and hydraulic rolling machines
Local exhaust system.	Drilling machines
Air freshening unit section	CIF Induction Furnace
	Boring machines
	Straightening machines
	Straightening tables
	Mese montaj
	Test machine

The human body uses thermal regulation mechanisms to maintain the internal temperature within the normal range. It involves heat exchange with the environment

through various processes such as convection, conduction, radiation, and evaporation of sweat. In this context, air temperature plays a crucial role in these heat exchanges [1].

The microclimate in the workplace plays a key role in ensuring the health, safety, and comfort of employees. If its parameters are not kept within adequate limits, negative effects on workers' well-being can occur, leading to increased heat stress, which can sometimes even lead to accidents [2].

When air temperatures, along with the other parameters of the microclimate, are different from the levels considered comfortable, environmental conditions are associated with thermal discomfort or, in extreme cases, heat stress. [7] This is a characteristic of very hot or very cold ambient conditions.

During working hours, the temperature in the rooms where workstations are located must be comfortable for employees, taking into account the working methods used, the work equipment, and the physical activities performed by the workers.

Ensuring adequate microclimate conditions in workplaces is the result of the efficiency of ventilation systems (natural, mechanical, or air conditioning).

The indicated method for determining the thermal ambiance complies with SR EN ISO 7730:2005 Moderate thermal ambiances. Analytical determination and interpretation of thermal comfort by calculating PMV and PPD indices and specifying local thermal comfort criteria [1].

In this standard, PMV is defined (predicts the mean value) which is an index that predicts the average value of votes of a large group of people on the 7-point thermal sensation scale (see Figure no. 1), based on the thermal equilibrium of the human body.

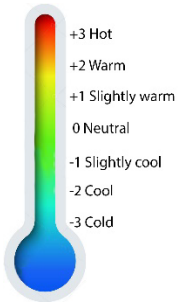

Fig.1. Seven-point thermal sensation scale

PPD (Predicted percentage dissatisfied) It is an indicator that provides a numerical estimate of the percentage of people who are thermally dissatisfied, whether they feel too cold or too hot. According to this International Standard, thermally dissatisfied individuals will choose "warm", "warm", "cold" or "cold" options on the 7-point thermal sensation scale [4].

When designing ventilation systems and installations intended for workspaces, whether they are offices or production areas, account must be taken primarily of the specifics of the work carried out, the technological processes involved, the activities

performed by workers, their physical requirements, as well as the constructive and functional characteristics of the workspaces and the number of persons/workstations involved.

The ventilation system used, in particular, that for distributing fresh air indoors and evacuating stale air outside, must ensure adequate airflow and a sufficient number of air changes per hour to maintain indoor air quality at an adequate level.

Fresh air intakes should be located in clean areas without risk of contamination (e.g. away from stale air vents, car parks, busy roads, or cooling towers). Air intake facilities should be equipped with filtration systems to ensure the air quality supplied. It is also important not to recirculate the air extracted from the areas.

Environmental factors include air temperature, radiant temperature, air velocity, and humidity, while personal factors include clothing insulation and metabolic heat. The air temperature is the ambient temperature next to the worker and is measured in degrees Celsius (°C). Radiant temperature is the heat emitted by an object and has a more significant influence than air temperature on how the body loses or gains heat in its environment. Air velocity is the speed of movement of air near the worker. The relative humidity is the ratio of the actual amount of water vapor in the air to the maximum amount of water vapor that air can contain at that temperature.

The insulation of clothing is an essential determinant of thermal comfort, and the ability of the employee to make appropriate adjustments to clothing to feel comfortable and the thermal insulation of personal protective equipment (PPE) are important aspects in this regard. Metabolic heat is directly related to the physical effort required for the workload. In addition, in certain circumstances, and in particular in outdoor workplaces, the thermal environment of the workplace may be influenced by climate change and global temperature rise [1].

2. MATERIALS AND METHODS

For measuring the microclimate in workplaces, the dedicated testo 400 equipment was used, which has metrological verification certificates for the measured parameters. In fig. 2 you can see the overall view of the device as well as its parts.

Fig. 2. TESTO 400 microclimate in workplaces
a) Testo 400 overview. b) Front view: 1-On/off button; 2-UI / Touchscreen, 3-Front camera, 4-Sample connection. c) Rear view: 1-camera; 2-differential pressure connectors; 3-magnet; 4- Strap attachment; 5-USB port, main connectors

Depending on the needs, the Testo 400 can concentrate various accessories (Figure 3) with wired or Bluetooth connectivity. In this mode, it can measure, temperature (hot wire probe), humidity, pressure, speed of air currents (with a vane probe for high precision), and CO_2 with a Bluetooth connection.

Fig. 3. TESTO 400 accessories: a) probe for measuring the speed of air currents, b) probe for CO2 and pressure, c) globe thermometer, d) pressure and speed probe, e) vane probe for measuring air currents, f) probe holder and carrying case.

According to ISO 7730:2005, for the calculation of thermal comfort indicators, PMV and PPD it is necessary to measure the indicators:

- Indoor air temperature;
- Average radiant temperature (measured using a globe thermometer);
- Relative air velocity;
- Relative air velocity;
- Atmospheric pressure;
- Relative humidity.

In addition, field observations must be made at each workplace on:

- The metabolic rate of workers W/m^2 (type of an active worker according to Table B.1 of ISO 7730:2005);
- Work performed by the worker W/m^2;
- Thermal insulation of the clothing worn by the worker m^2K/W (to be chosen from the table depending on the clothing worn);
- Clothing surface factor (to be chosen from the table) [6].

3. RESULTS AND DISCUSSION

In September 2023, several series of measurements were carried out at a company that performs hot metal processing. Given the object of activity of this company, it was expected that the conditions of microclimate parameters would in most cases be located in the "warm" work environment.

To interpret the obtained data, PMV (Predicted mean vote) and PPD (Predicted percentage dissatisfied) calculation indices were used, and for this, it was necessary to estimate metabolic rate indices and clothing isolation:

- The metabolic rate index was estimated at 1.9, which is the specific value of standing activities.

– The Daily Clothing Isolation Index was estimated at 0.9, which is the specific value of clothing: shoes, pants, T-shirts, socks, and underwear.

In the work areas presented in Table No. 2, the calculated values of PPD are between 23.2 and 97.8%, which represents the percentage of people possibly dissatisfied with the microclimate parameters of the working environment. Of the total jobs analyzed, around 59% of workers are dissatisfied with microclimate parameters at work.

Table 2. **Measured temperature results as well as PMV and PPD indicators**

Section	Air temp. [°C]	Average radiant temp. [°C]	Relative air velocity [m/s]	Relative humidity [%]	Clothing [clo]	Metabolic rate [met]	PMV	PPD [%]	Sensation scale
Debiting press 100 tf	27	25,2	0,13	43,8	0,9	1,90	1,42	46,5	Hot
Preparation workshop 1	34,1	31	0,09	34	0,9	1,90	2,37	90,5	Hot
Preparation Workshop - Laminor 1	36,2	31,8	0,12	31,7	0,9	1,90	2,61	95,5	Hot
Preparation Workshop – ICB 2	38,5	31,8	0,11	31	0,9	1,90	2,80	97,8	Hot
Thermal treatments workshop	29,4	27,3	0,09	41,2	0,9	1,90	1,77	65,6	Hot
Thermal treatments workshop - Rejna and EZM	31,1	30,6	0,12	35,9	0,9	1,90	2,11	81,5	Hot
Thermal treatments workshop – Milling area	28,2	26,2	0,09	41	0,9	1,90	1,59	56,0	Hot
Laminor and the robotic cell	27,1	26	0,09	43	0,9	1,90	1,50	51,0	Hot
Thermal treatments workshop – Lam. Hille 1	31,2	26,7	0,08	43	0,9	1,90	1,89	71,6	Hot
Montage – Gutmann 1	23,9	22	0,1	55,1	0,9	1,90	1,01	26,6	Hot
Assembly - Final painting	25,2	23	0,09	49,7	0,9	1,90	1,17	33,9	Hot
Installation – Weiss and Probat	24,1	22,8	0,1	51,6	0,9	1,90	1,06	28,9	Hot
Assembly – Trapezoidal assembly and painting	23,8	21,4	0,1	48,1	0,9	1,90	0,92	23,2	Warm
Accessory and finished warehouses – Accessory warehouse	30,5	22,9	0,2	54,5	0,9	1,90	1,68	61	Hot

Calculating PMV values shows that work environments are considered "Hot", only in one case was recorded "Warm" work environment.

In figure 4 represented graphs of some of the most representative jobs, in which we have the PPD index between 23.17 and 90.5%.

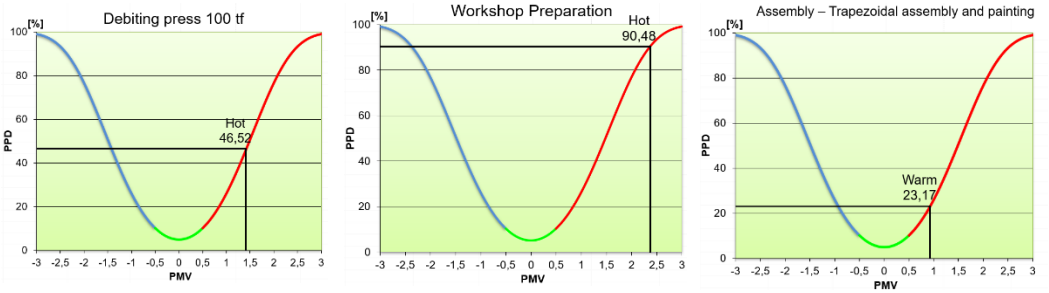

Fig. 4. Graphical representation of the PPD index for jobs: cutting press 100 tf, preparation workshop, and Trapez-painting assembly.

From these graphs, it follows that in all workplaces the thermal comfort index is considered warm and very hot.

Plotting the percentage values of workers dissatisfied with the work environment, high and very high values can be observed in almost all workplaces.

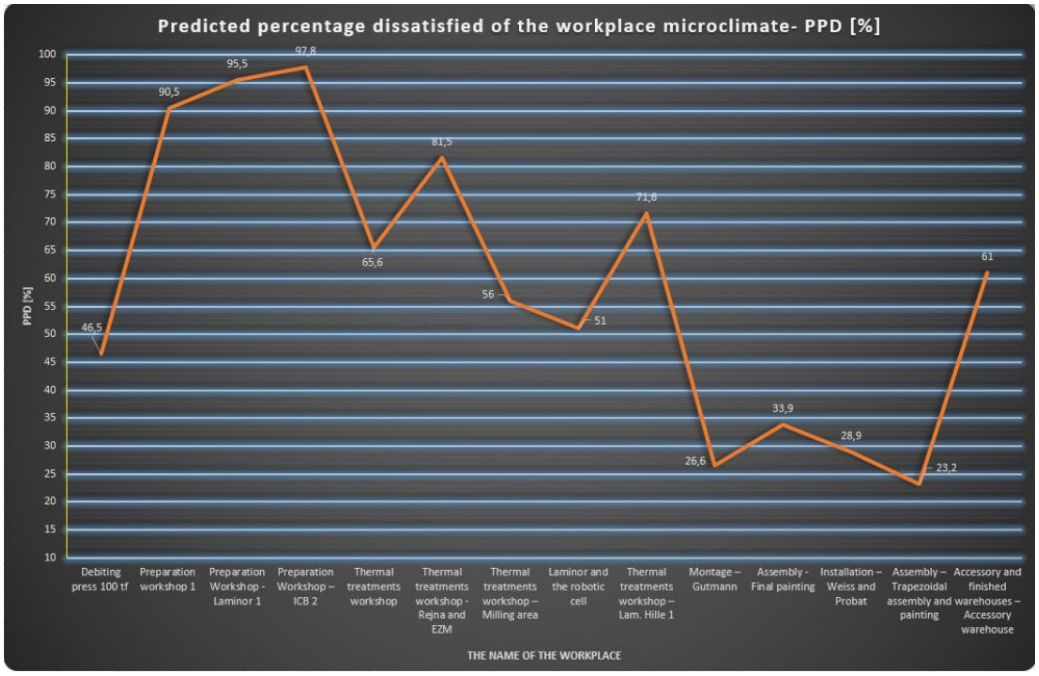

Fig. 5. Graphical representation of the PPD index for all jobs.

3.1. Measures to normalize working conditions.

The main factor in increased discomfort at work is air temperature falling in the range of 23.8 and 38.5°C. Normally, air temperature in warm climates (due to the specificity of activities) should be in the range of 23 to 26°C.

As a method of lowering the temperature in workplaces, it must be analyzed according to the characteristics of each workplace. From field observations, at all workplaces, there are fresh air supply or exhaust installations aimed at significantly reducing the temperature in the working environment. In many workplaces, these exhaust installations or air ducts have been switched off or decreased suction power by workers because there is too much current.

Another important factor in ensuring the right climate in workplaces is the speed of air currents. The measurements resulted in speeds ranging from 0.08 to 0.25 m/s, which indicates very low values.

Airspeed can maintain the feeling of thermal comfort, so in this case, it can be recommended to increase the air velocity, which leads to lowering the temperature and implicitly to falling within the recommended thermal comfort limits.

According to ASHRAE-55, there is a close relationship between air velocity and temperature, so if the air velocity is increased by 0.9 m/s, the air temperature can decrease by 1.8°C. [2, 3]. Based on this conversion, it can be considered that if at all workplaces the speed of the airflow in the exhaust or air-conditioning system is increased, the temperature felt by the worker will decrease, according to Table No. 3.

Table 3. **The values when the temperature decreases by 1.8 ^{0}C**

Section	Air temp. [°C]	Average radiant temp. [°C]	Relative air velocity [m/s]	Relative humidity [%]	Clothing [clo]	Metabolic rate [met]	PMV	PPD [%]	Sensation scale
Debiting press 100 tf	24	22,2	1,03	43,8	0,9	1,90	0,68	14,9	Warm
Preparation workshop 1	31,1	28	0,99	34	0,9	1,90	1,93	73,9	Hot
Preparation Workshop - Laminor 1	33,2	28,8	1,02	31,7	0,9	1,90	2,26	87,2	Hot
Preparation Workshop – ICB 2	35,5	28,8	1,01	31	0,9	1,90	2,60	95,3	Hot
Thermal treatments workshop	26,4	24,3	0,99	41,2	0,9	1,90	1,12	31,6	Hot
Thermal treatments workshop - Rejna and EZM	28,1	27,6	1,02	35,9	0,9	1,90	1,49	50,3	Hot

Thermal treatments workshop – Milling area	25,2	23,2	0,99	41	0,9	1,90	0,89	22,0	Warm
Laminor and the robotic cell	24,1	23	0,99	43	0,9	1,90	0,73	16,4	Warm
Thermal treatments workshop – Lam. Hille 1	28,2	23,7	0,98	43	0,9	1,90	1,37	44,2	Hot
Montage – Gutmann 1	20,9	19	1	55,1	0,9	1,90	0,14	5,4	Warm
Assembly - Final painting	22,2	20	0,99	49,7	0,9	1,90	0,36	7,7	Warm
Installation – Weiss and Probat	21,1	19,8	1	51,6	0,9	1,90	0,19	5,8	Warm
Assembly – Trapezoidal assembly and painting	20,8	18,4	1	48,1	0,9	1,90	0,07	5,1	Warm
Accessory and finished warehouses – Accessory warehouse	27,5	19,9	1,1	54,5	0,9	1,90	1,17	34,1	Hot

In this table, it follows that the calculated values of PPD are between 5.1 and 95.3%, which is the percentage of people possibly dissatisfied with the microclimate parameters of the working environment. Of the total jobs analyzed, about 35% of workers are dissatisfied with the microclimate parameters at work, much lower than 59% if the speed of air currents was lower. Also, of the total jobs, at 7 out of 14 jobs, the temperature sensation scale is very hot (Hot), compared to previous measurements, in which the discomfort scale was at 13 jobs out of 14.

In conclusion, the method of increasing the speed of air currents in workplaces (local ventilation) is quite effective in ensuring normal working conditions, but not sufficient.

To bring into normal parameters the thermal comfort at the analyzed workplaces, the working temperatures were recalculated, so that the thermal comfort indices are within normal limits. In this way, the graph was made showing the difference between the measured temperature and the optimum temperature for workplaces to be in normal working conditions (in terms of thermal comfort). Thus, the recommended temperatures are between 21.5 and 23.6°C, and the airflow velocities are between 0.2-2.3 m/s.

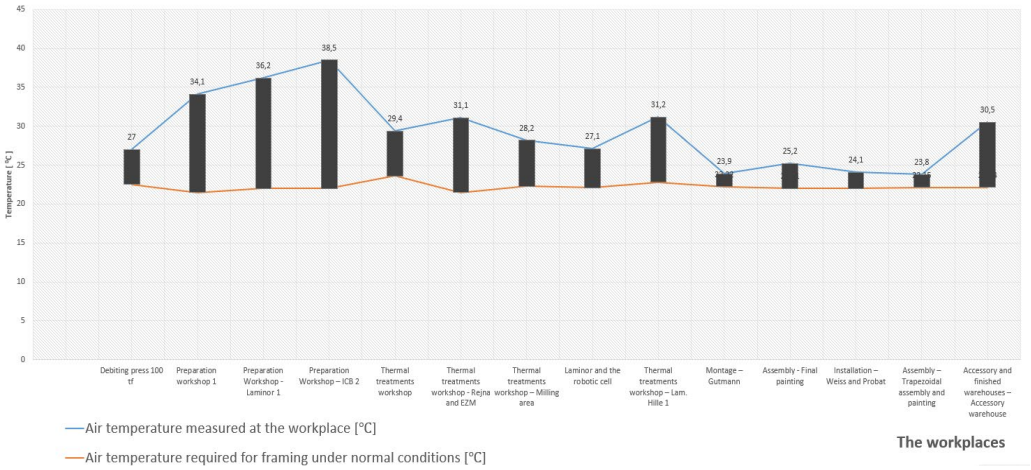

Fig.6. The difference between the measured temperature and the optimum temperature for which working conditions are under normal working conditions.

For these workplaces, both technical and organizational measures are recommended to normalize working conditions in terms of thermal index. These measures are employers to purchase workers' clothing adapted to the ambient temperature; enable and incentivize workers to report any heat stress they experience in the workplace; ensure regular medical check-ups of workers and monitor health problems that are a risk factor when working under heat stress. [4] It is also important to provide adequate training to workers on heat stress and measures to avoid it. In addition, reducing or changing working time during heat waves can be considered [5].

At the same time, it is recommended to improve local ventilation by dislodging warm air from parts that need to be processed at high temperatures. It is also recommended to improve general and local ventilation, and where possible even implement a mixed ventilation system [6].

4. CONCLUSIONS

The microclimate in the workplace plays a key role in ensuring the health, safety, and comfort of employees. If its parameters are not kept within adequate limits, negative effects on workers' well-being can occur, leading to increased heat stress, which can sometimes even lead to accidents at work.

The purpose of the work is to assess the degree of comfort at 14 workplaces performing hot metal processing and to identify measures to normalize working conditions. For this, thermal comfort was determined by calculating PMV and PPD indices and specifying local thermal comfort criteria following ISO 7730:2005. In this regard, factors of the working environment include air temperature, radiant temperature, air velocity, and relative humidity, as well as personal factors including clothing insulation and metabolic heat.

In September 2023, several series of measurements were carried out at a

company that performs hot metal processing.

In the analyzed work areas at the 14 workplaces, the calculated values of PPD are between 23.2 and 97.8%, which represents the percentage of people possibly dissatisfied with the microclimate parameters of the working environment. Calculating PMV values shows that work environments are considered "Hot", only in one case was recorded "Warm" work environment.

The main factor in increased discomfort at work is air temperature falling in the range of 23.8 and 38.5 ^{0}C. Normally, air temperature in warm climates (due to the specificity of activities) should be in the range of 23 to 26^{o}C.

Airspeed can maintain the feeling of thermal comfort, so in this case, it can be recommended to increase the air velocity, which leads to lowering the temperature and implicitly to falling within the recommended thermal comfort limits.

There is a close relationship between air velocity and temperature, so if the airspeed increases, the air temperature will decrease. Correlating this, if the air velocity increases by only 0.9 m/s, out of all jobs, only in 7 out of 14 jobs, the temperature sensation scale is very hot (Hot), in the rest decreased to the thermal sensation of warm.

To bring into normal parameters the thermal comfort at the analyzed workplaces, the working temperatures were recalculated, so that the thermal comfort indices are within normal limits, the recommended temperatures must be between 21.5 and 23.6 ^{0}C, and the air current speeds must be between 0.2-2.3 m/s.

For these workplaces, both technical and organizational measures are recommended to normalize working conditions in terms of thermal index. At the same time, it is recommended to improve local ventilation by dislodging warm air from parts that need to be processed at high temperatures. It is also recommended to improve general and local ventilation, and where possible even implement a mixed ventilation system.

Acknowledgements

The current paper was carried out through the Nucleu Program within the National Research Development and Innovation Plan 2022-2027, carried out with the support of MCID, project no. PN 23 32 01 01 and IOSIN PCDIEX.

REFERENCES

[1]. **Rînjea, C., Chivu, O.R., Darabont, D.C., Feier, A.I., Borda, C., Gheorghe, M. and Nitoi, D.F.** *Influence of the thermal environment on occupational health and safety in automotive industry: a case study.* Int. J. Environ. Res. Public Health 2022, 19(14), 8572, p.8672; https://doi.org/10.3390/ijerph19148572.

[2]. **De Faria, L., Cook, M., Loveday, D., Angelopoulos, C., Manu, S., & Shukla, Y.** *Sizing natural ventilation systems for cooling: The potential of NV systems to deliver thermal comfort while reducing energy demands of multi-storey residential buildings in India.*

Conference: PLEA 2018 - Smart and Healthy within the 2-degree LimitAt: Hong Kong - 2018

[3]. ANSI/ASHRAE Standard 55-2010 Thermal Environmental Conditions for Human Occupancy. https://lorisweb.com/CMGT235/DIS06/ASHRAE-55-2010.pdf.

[4]. **Sulzer, M., Christen, A., Matzarakis, A.** *A low-cost sensor network for real-time thermal stress monitoring and communication in occupational contexts*. Sensors, 2022, 22(5), 1828.

[5]. **Li, F. L., Chien, W. C., Chung, C. H., Lai, C. Y., Tzeng, N. S.** *Real-world evidence for the association between heat-related illness and the risk of psychiatric disorders in Taiwan*. Int. J. Environ. Res. Public Health 2022, 19(13), 8087.

[6]. **Ismail, A. R., Jusoh, N., Zulkifli, R., Sopian, K., Deros, B. M.** *Thermal comfort assessment: A case study at Malaysian automotive industry*. American Journal of Applied Sciences, 2009, 6(8), 1495.

[7]. Thermal Stress on the Work Place. Available online: https://www.canada.ca/en/employment-social-development/services/health-safety/reports/thermal-stress-work-place.html, (Date modified:2023-01-27).

This article was reviewed and accepted for presentation and publication within the 11th edition of the International Multidisciplinary Symposium "UNIVERSITARIA SIMPRO 2024