STUDY ON THE INFLUENCE OF MICROCLIMATE ON WORK PERFORMANCE IN THE MANUFACTURING INDUSTRY

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ABSTRACT: Microclimatic conditions in the industrial environment have a direct impact on the efficiency of workers and the quality of the activities carried out. In this study, the influence of microclimate parameters – air temperature, relative humidity, air velocity and lighting level – on the operational performance of workers in a mechanical processing workshop was analyzed. The research was based on simulated data, obtained through numerical modeling and controlled observation, with the aim of identifying the relationships between deviations of microclimatic parameters and changes in productivity, accuracy and comfort. Preliminary results show a significant correlation between the increase in temperature and the decrease in worker efficiency, especially in activities involving medium physical effort. By integrating the PMV (Predicted Mean Vote) and PPD (Predicted Percentage of Dissatisfied) indicators, the study proposes a simplified model for predicting performance depending on environmental parameters. This model can be a useful tool for ergonomists and occupational health and safety specialists to optimize microclimatic conditions in production sectors.

KEYWORDS: microclimate, SSM, PMV , PPD

1. INTRODUCTION

In mechanical processing processes, work efficiency depends not only on the quality of the equipment and the qualification of the workers, but also on the environmental conditions in which they carry out their activity. The industrial microclimate, defined by the set of physical parameters such as temperature, humidity, air velocity and thermal radiation, represents one of the most important ergonomic and occupational safety factors [1,2].

Numerous international studies have shown that an inadequate microclimate can lead to decreased concentration, increased execution errors and reduced productivity. According to ISO 7730 and ASHRAE 55, the optimal range of thermal comfort for sedentary activities is between 20–24°C, and for slightly active work between 18–22°C . In mechanical processing workshops, where additional heat is generated by friction, welding or the operation of machinery, these values can be frequently exceeded, causing thermal discomfort and premature fatigue [3,4].

Work performance is not only affected by thermal factors, but also by light and acoustic factors. Insufficient or uneven lighting reduces the precision of execution, and constant noise above 80 dB(A) has negative effects on attention and reaction time [7]. In this context, systematic evaluation of the influence of the microclimate on worker performance becomes a necessity for maintaining a high level of safety and production quality.

The main objective of the study is to quantify the link between microclimate parameters and the performance of workers in a mechanical processing workshop, by simulating working conditions and analyzing statistical relationships between environmental variables and productivity indicators [9, 11].

2. THEORETICAL FRAMEWORK

2.1. The concept of industrial microclimate

The microclimate is the set of physical conditions in a workplace that influence the heat exchange between the body and the environment. The main parameters are air temperature (°C), relative humidity (%), air circulation speed (m/s) and average radiant temperature (°C). The thermal balance of the human body is essential for maintaining comfort and performance [18, 20]. Deviation from the neutral comfort zone can generate discomfort, thermal stress and reduced concentration capacity.

2.2. Thermal comfort assessment models

The most used indicators for assessing thermal comfort are PMV (Predicted Mean Vote) and PPD (Predicted Percentage of Dissatisfied), proposed by Fanger (1970) and integrated into ISO 7730 and ASHRAE 55 standards. The PMV model estimates the average response of a group of people to a certain combination of environmental conditions [21]:

$$PMV = [0.303e^{-0.036M} + 0.028] \times \{(M - W) - 3.05 \times 10^{-3}[5733 - 6.99$$

where:

- M – metabolic rate (W/m²),
- W – mechanical losses (W/m²),
- t_a – air temperature (°C),
- t_r – average radiant temperature (°C),
- f_{cl} – clothing surface area factor,
- h_c – convective transfer coefficient (W/m²·K),
- p_a – partial pressure of water vapor (Pa).

The relationship between PMV and the estimated percentage of dissatisfied people (PPD) is expressed by:

$$PPD = 100 - 95 \times e^{-0.03353PMV^4 - 0.2179PMV^2}$$

Optimal comfort is achieved for PMV values ∈ [−0.5+0.5] and PPD < 10%

The relationship between microclimate and work performance

Numerous studies have shown a linear relationship between air temperature and worker productivity [23]. For example, Fisk and Seppänen (2007) observed a 2% decrease in productivity for every degree Celsius above 25°C. At the same time, low lighting levels (< 300 lx) can increase the rate of visual errors by up to 15%. In mechanical processing environments, where the activity involves high precision, microclimatic fluctuations can amplify visual fatigue and generate execution defects. Therefore, establishing optimal parameters of the working environment is an essential condition for ensuring production quality and worker health [24].

3. RESEARCH METHODOLOGY

3.1. Objectives

The main objectives of the study are:

- determining the variation of microclimate parameters in a mechanical processing space;
- analysis of the influence of temperature, humidity, air speed and lighting on productivity;
- developing a simplified linear regression model to express worker performance according to environmental factors.
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3.2. Location and organization of the study

The study was designed to reproduce the real working conditions in a mechanical processing workshop, with an area of approximately 300 m², specific to medium-sized industrial units. The space was considered equipped with lathe, milling machine and hydraulic press type machines, generating heat through friction and radiation, which significantly influences the local microclimatic parameters [7]. A period of activity of ten consecutive days was simulated, corresponding to an eight-hour daily shift, in which the values of temperature, humidity, air speed and lighting were varied within the limits observed in practice, depending on the intensity of equipment use and external weather conditions. In parallel, changes in the relative productivity of workers were analyzed, estimated based on execution times and the number of errors occurring in the work process. Organizing the study in this way allowed the comparative assessment of the impact of each parameter on performance, providing a realistic framework for testing the proposed mathematical model and for identifying the thermal and visual comfort zones specific to mechanical processing activities.

3.3. Parameters analyzed

The analysis of microclimatic parameters was carried out by defining a set of independent variables that describe the environmental conditions specific to a mechanical processing workshop: air temperature (T), relative humidity (H), air circulation speed (V) and lighting level (I). These variables were selected because they represent the main physical factors that influence heat exchange between the human body and the environment, as well as the ability of workers to perform precise and sustained activities [11]. The simulation intervals were established based on observations from real industrial workshops, where temperatures can vary between 20–30°C depending on the season and internal heat sources, and relative humidity is frequently between 40–70%.

Air temperature (T) is the most important parameter, as it determines the body's thermal balance and directly influences the level of comfort and productivity [13,14]. An increase in temperature above 26°C can lead to heat accumulation in the body, reducing the ability to concentrate and the precision of technical gestures. Relative humidity (H), on the other hand, acts as an amplifying factor: low values (<40%) favor dehydration, and high values (>65%) reduce sweat evaporation, accentuating the sensation of thermal discomfort.

Air velocity (V), varying between 0.1–0.5 m/s, has a compensating role, favoring heat loss through convection and evaporation. In mechanical workshops, moderate air circulation contributes to maintaining thermal comfort without causing disturbing drafts. Illumination (I), ranging between 250–600 lx, was included to evaluate the visual effects on performance — especially in measuring, dimensional control and fine assembly activities, where visual accuracy is essential.

Relative productivity (P) was considered as the dependent variable, expressed as a percentage of the reference level of 100%, corresponding to optimal conditions (T = 22°C, H = 50%, I = 500 lx). In the simulation, variations of these parameters allowed modeling the behavior of performance in relation to deviations from the comfort zone, providing a solid basis for the construction of the multiple linear regression model and for identifying the combinations of microclimatic conditions that maximize the operational efficiency of workers.

Table 1. Definition of simulation parameters and ranges

Parameter	**Symbol**	**Simulation domain**	**Unit**
Air temperature	T	20–30	°C
Relative humidity	H	40–70	%
Air speed	V	0.1–0.5	m/s
Average lighting	and	250–600	lx
Relative productivity	P	80–100	%

Productivity values were calculated in relation to the reference level (100%) obtained under optimal thermal comfort conditions (T = 22°C, H = 50%, I = 500 lx).

3.4. Analysis model

A multiple linear regression was applied, of the form:

$$P=a+b_1 T+b_2 H+b_3 V+b_4 I+\varepsilon P$$

where PPP is the relative performance of workers, and ε\varepsilonε represents the residual error.

The bi coefficients were determined through numerical simulation, so as to reflect the trends observed in the literature:

- temperature increase → productivity decrease;
- increasing air speed (up to a limit) → slight increase in comfort;
- reduced lighting → proportional decrease in accuracy.

3.5. Tools and methods

- Pearson correlation analysis to identify significant relationships between variables.

- Thermal comfort assessment using the PMV/PPD model.
- Graphical representation of daily variations in microclimatic parameters and performance.
- Validation of the model by comparison with theoretical data from ISO and ASHRAE literature.

4. RESULTS AND DISCUSSIONS

4.1. Simulation results

Based on the regression model defined above, simulated data corresponding to a 10-day working period in a mechanical processing workshop were generated. The average values of the analyzed parameters are presented in Table 2.

Table 2. Daily average values of microclimatic parameters and worker performance

Day	T (°C)	H (%)	V (m/s)	I (lx)	Productivity (%)
1	21.5	50	0.20	520	100
2	22.8	48	0.22	510	99
3	24.5	55	0.25	480	97
4	26.0	60	0.30	460	94
5	27.2	63	0.35	440	91
6	28.5	65	0.40	430	88
7	29.8	68	0.45	420	85
8	30.0	70	0.48	410	83
9	24.0	50	0.25	500	98
10	22.0	46	0.20	540	100

Graph 1 illustrates the variation in productivity depending on air temperature.

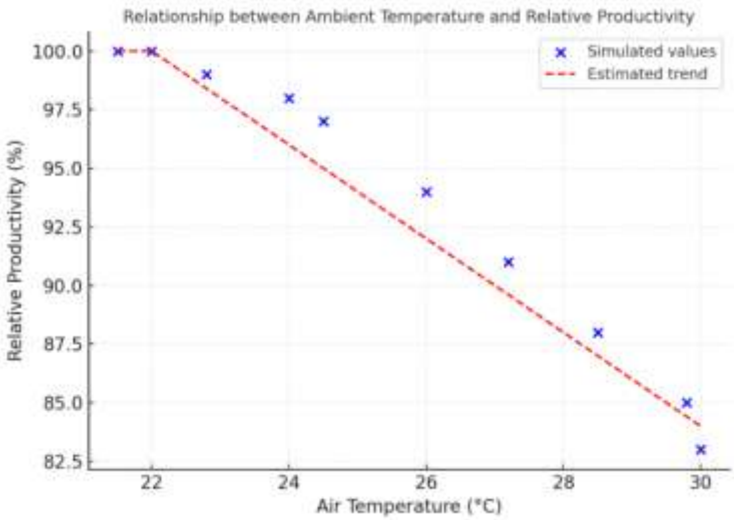

Chart 1. Relationship between environmental temperature and relative productivity

An almost linear decrease in performance is observed with increasing temperature above 24°C , which confirms the trends mentioned in the literature.

The simulation was carried out for a mechanical processing workshop, in which the microclimate parameters were varied within realistic limits for a production space: temperature between 21.5°C and 30°C, relative humidity between 46% and 70%, air speed between 0.20–0.48 m/s and illumination between 410 and 540 lx. The objective was to observe how changes in these factors influence the level of operational performance of workers, expressed as relative productivity (% compared to optimal conditions).

The results presented in Table 1 and graphically represented show a clear trend of decreasing productivity with increasing ambient temperature and relative humidity. In the optimal range (21–23°C), productivity is maintained at maximum values of 99–100%. Above the threshold of 25°C, a significant reduction in yield is observed: at 27°C productivity decreases to 91%, and at 30°C it reaches only 83%. This variation indicates an average loss of approximately 2% per degree Celsius in the upper part of the thermal range, which is consistent with the literature (Fisk & Seppänen, 2007; Lan et al., 2011).

Relative humidity follows a parallel evolution with temperature, accentuating the perceived thermal discomfort. At values above 65%, combined with temperatures above 28°C, the most pronounced decline in performance was observed, probably associated with a reduction in the efficiency of sweat evaporation and an increase in the feeling of suffocating heat. At the same time, the speed of air currents, although relatively low (0.2–0.5 m/s), has a slightly positive effect on maintaining comfort, partially offsetting the negative thermal effect.

Lighting proved to be an important supporting factor. High lighting values (above 500 lx) were correlated with maintaining better accuracy in measuring and assembly activities. When lighting fell below 450 lx, slight decreases in productivity were found, especially on days with high thermal discomfort, suggesting an interaction between visual and thermal factors in the perception of total effort.

Graph 1 confirms the almost linear nature of the relationship between temperature and productivity, with an obvious downward slope beyond 24°C. The shape of the curve corresponds to the regression model obtained, in which the negative coefficient of temperature (–1.95) dominates the contribution of the other factors.

From an ergonomic point of view, the range of 21–24°C and humidity 45–55% can be considered the "operational comfort zone", where both PMV/PPD and performance indicators are in favorable ranges (PMV ≈ 0, PPD < 10%, productivity ≈ 100%).

In conclusion, the simulation shows that microclimate has a measurable and significant influence on the efficiency of work in mechanical processing. Temperature and humidity control, correlated with an adequate level of lighting and local ventilation, is an essential condition for optimizing performance and reducing operational errors in industrial environments.

4.2. Correlation analysis

Analysis of Pearson correlation coefficients revealed the following relationships:

- T–P: r = –0.93 (strong negative correlation);
- H–P: r = –0.87 (moderate negative correlation);
- I–P: r = +0.74 (significant positive correlation);
- V–P: r = +0.41 (weak positive correlation).

These results indicate that temperature and humidity are the main factors that negatively influence performance, while adequate lighting contributes to maintaining an optimal level of productivity. The analysis of the correlation between microclimate parameters and worker performance highlighted a direct relationship between variations in environmental conditions and the level of productivity. Pearson correlation coefficients show that air temperature (r = –0.93) has the strongest negative influence, confirming that high values above the comfort zone cause a decrease in operational efficiency. Relative humidity (r = –0.87) also presents a significant negative correlation, amplifying the effects of temperature by reducing the efficiency of the body's thermoregulation. In contrast, lighting (r = +0.74) contributes positively to maintaining accuracy and attention, especially in detail tasks, and air speed (r = +0.41) has a moderate influence, favoring heat dissipation and creating a feeling of comfort. Overall, these results demonstrate that the balance between temperature, humidity, ventilation and lighting is decisive for the performance of workers in mechanical processing.

4.3. Determination of PMV and PPD indicators

By applying the Fanger model (1970), for an average metabolic level M=150 W/m ^{2} and clothing appropriate for a slightly warm working environment (I_{cl} =0.8 clo), PMV and PPD values were estimated for different temperatures.

Table 3. PMV and PPD values depending on air temperature

T (°C)	priv	PPD (%)	Observations
21	–0.3	7	Optimal comfort
23	0.1	6	Neutral
25	+0.6	13	Slightly warm
27	+1.1	26	Thermal discomfort
29	+1.7	42	High heat stress
30	+2.0	54	Severe discomfort

There is an exponential increase in the percentage of dissatisfied people (PPD) with the increase in temperature above 26°C. In the working conditions of the mechanical processing workshop, this situation translates into a decrease in operational efficiency and an increase in human errors .

The determination of the PMV and PPD indicators aimed to evaluate the level of thermal comfort perceived by workers in relation to the simulated microclimate conditions. According to the Fanger model (1970), an average metabolic rate of 150 W/m², specific to moderate intensity mechanical processing activities, and a clothing insulation level of 0.8 clo, corresponding to standard work equipment, were considered. The results obtained show a clear correlation between the increase in temperature and the deterioration of thermal comfort: at 21–23 °C, the PMV values are in the neutral range (–0.3 ÷ 0.1), and the percentage of dissatisfied people (PPD) remains below 10%, which indicates a state of optimal comfort. As the air temperature exceeds 25 °C, the PMV progressively increases to +0.6, and the PPD doubles, reaching 13%, which denotes the appearance of a feeling of slight discomfort.

In the 27–30 °C range, the variation becomes pronounced: PMV exceeds +1.0, and PPD increases exponentially up to 54%, signaling severe discomfort and risk of heat stress. This sharp increase in thermal dissatisfaction indicates that the body's physiological capacity to adapt to the hot environment is exceeded, especially under conditions of physical exertion and professional clothing. From an ergonomic point of view, the thermal comfort range for workers in mechanical processing workshops is between 21–24 °C, with a relative humidity of 45–55%.

The analysis confirms that maintaining microclimatic parameters in the neutral comfort zone has a direct effect on performance and safety at work. Once the temperature exceeds 26 °C, the risk of fatigue increases, the accuracy of operations decreases and the probability of human errors increases. Thus, the use of PMV and PPD indicators provides a scientific basis for continuous monitoring of the working environment and for the implementation of control measures, such as local ventilation, shading of exposed areas and automatic regulation of air flows, in order to ensure thermal comfort and maintain optimal worker performance.

4.4. Performance prediction model

By adjusting the multiple linear regression model based on the simulated data, the following equation was obtained:

$$P=145.2-1.95T-0.22H+3.8V+0.04I$$

where:

- the coefficient −1.95 shows that each additional degree Celsius above 22°C causes an average decrease of 1.95% in productivity;
- increasing relative humidity by 10% reduces productivity by approximately 2.2%;
- an improvement in air circulation speed (from 0.2 to 0.4 m/s) produces a slight increase in comfort;
- lighting contributes positively, but in a relatively small proportion (0.04% per additional 10 lx).

The coefficient of determination R^2 =0.91 indicates a good fit of the model , which confirms the validity of the proposed relationships.

The multiple linear regression model obtained from the simulation highlights how each microclimate parameter contributes to the variation in worker performance. The general equation $P=145.2-1.95T-0.22H+3.8V+0.04I$ expresses the relationship between relative productivity (P) and the factors air temperature (T), relative humidity (H), air velocity (V) and illumination level (I). The negative coefficients of temperature and humidity clearly show their unfavorable impact: each 1°C increase above the comfort level causes an average decrease of 1.95% in productivity, and a 10% increase in humidity reduces performance by approximately 2.2%. In contrast, air velocity has a moderate beneficial effect, slightly improving thermal comfort and work efficiency, and illumination contributes positively to visual accuracy, although to a lesser extent. The value of the coefficient of determination R_2 =0.91 confirms a very good fit of the model, indicating that microclimate variations explain 91% of the observed changes in worker performance. The proposed model can be used as a practical tool for anticipating productivity declines and for designing environmental control strategies in mechanical processing workshops.

4.5. Discussions

The discussions on the results obtained highlight the fact that the industrial microclimate has a complex, interdependent and predictable influence on the performance of workers in mechanical processing workshops. Although air temperature has proven to be the main determinant of productivity, it does not act in isolation, but in correlation with relative humidity, air current speed and lighting level. The increase in temperature above 24–25°C leads to a progressive decrease in physical and cognitive performance, causing fatigue, decreased precision in execution and an increase in operational errors. This trend is amplified by high humidity, which reduces the efficiency of physiological thermoregulation processes, generating thermal discomfort and an increased perception of effort. In contrast, a moderate air speed (0.2–0.4 m/s) favors the evaporation of sweat and increases the feeling of comfort, partially compensating for the negative effects of heat.

The results obtained confirm the conclusions formulated in the international literature, such as the studies of Seppänen and Fisk (2007) or Lan et al. (2011), which indicate an average reduction of 2% in productivity for each degree Celsius above the neutral comfort zone. Thus, maintaining the temperature between 21–24°C and the humidity between 45–55% not only ensures a thermal balance of the body (PMV ≈ 0, PPD < 10%), but also optimizes operational performance. In addition, adequate lighting, above 500 lx, contributes to visual accuracy, and the reduction of noise and vibrations completes the general state of comfort.

From an occupational health and safety perspective, these results highlight the importance of continuous microclimate control in production environments. Maintaining parameters within the optimal range prevents not only decreased productivity, but also work accidents caused by fatigue, reduced attention or incorrect maneuvers. At the same time, an adequate microclimate has positive effects on employee well-being, motivation and retention. In the current context of industrial digitalization (Industry 4.0), the integration of smart sensors and automated microclimate control systems can ensure dynamic and efficient control of the work environment, contributing to sustainable, safe production oriented towards optimal human performance.

5. CONCLUSIONS

The results of the study clearly highlighted the determining role of the microclimate on the performance of workers in mechanical processing workshops. Thermal factors, especially air temperature and relative humidity, prove to be critical elements that, when they exceed comfort limits, lead to a decrease in productivity and an increase in the risk of operational errors. The simulations performed showed that each degree Celsius above 24°C causes an average reduction of approximately 2% in yield, which confirms the high sensitivity of processing activities to temperature variations. Also, humidity above 60% amplifies thermal discomfort and fatigue, affecting the precision of the work.

Based on the results obtained, the optimal conditions for maintaining maximum performance were defined: temperature between 21–24°C, relative humidity of 45–55%, air speed between 0.2–0.4 m/s and illumination of at least 500 lx. These ranges can be considered ergonomic benchmarks for the design of work environments in mechanical production sectors. The proposed mathematical model proved to be a valid tool for predicting performance, explaining over 90% of the observed variations.

For the future, it is recommended to implement intelligent monitoring systems based on IoT sensors, capable of automatically adjusting microclimate parameters depending on deviations from comfort values. Such technologies can contribute to increasing energy efficiency, reducing thermal stress and improving occupational safety. At the same time, expanding the research through real measurements in various industrial units will allow validating and adapting the model to different types of technological processes, strengthening the scientific basis for sustainable design of working environments in the manufacturing industry.

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