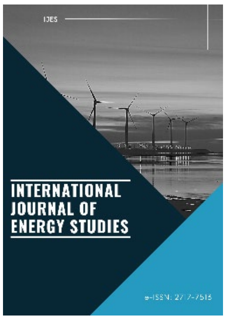
INTERNATIONAL JOURNAL OF ENERGY STUDIES

e-ISSN: 2717-7513 (ONLINE); homepage: https://dergipark.org.tr/en/pub/ijes



Research Article

Int J Energy Studies 2024; 9(4): 849-865

DOI: 10.58559/ijes.1516469

Received : 15 Jul 2024
Revised : 27 Sep 2024
Accepted : 16 Oct 2024

Assessment of thermal comfort preferences of industrial facility workers

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Highlights

- Calculation of PMV-PPD values of industrial facility workers.
- The effect of age, gender, clothing, and activity levels of the workers in terms of thermal comfort.
- Statistical analysis of thermal comfort preferences of workers.

You can cite this article as: Caner İ, Özbağ Ş, İlten N. Assessment of thermal comfort preferences of industrial facility workers. Int J Energy Studies 2024; 9(4): 849-865.

ABSTRACT

Ensuring thermal comfort in industrial facilities enhances worker productivity and well-being. Achieving optimal conditions necessitates efficient utilisation of HVAC systems. Therefore, ongoing monitoring and improvement are essential to maintain suitable thermal environments within workspaces. This study focused on evaluating the environmental conditions of a facility located in Bolu province about its workforce. Measurements and surveys were conducted to assess conditions separately during summer, winter, and spring. Evaluations considered factors such as age, gender, clothing, and activity levels of the workers. Further analysis of PMV values showed significant differences in thermal comfort, except during heating and autumn, with workers' subjective perceptions aligning closely with their acceptance of thermal conditions. Individual preferences were especially influential, particularly outside of cooling periods. While no significant differences were found based on gender or age, activity levels significantly affected thermal comfort, highlighting the importance of considering these factors in industrial settings.

Keywords: Thermal comfort, PMV-PPD, Statistical analysis, Industrial facility

1. INTRODUCTION

The pace of urbanization has accelerated significantly since the 18th and 19th centuries, driven by inventions that fueled mechanization and production during the Industrial Revolution. Today, a substantial portion of energy consumption in both developed and developing countries is attributed to heating and cooling buildings. Given the constraints of limited energy resources and the environmental impacts of excessive energy use, enhancing energy efficiency in buildings is crucial for sustainable development. Achieving this goal hinges on a deep understanding of the thermal comfort of building occupants. Effective strategies to reduce energy consumption for heating and cooling must prioritize the comfort and productivity of users [1]. As technology advances and living standards improve, the importance of comfort in living spaces has become increasingly pronounced [2]. This underscores the necessity of integrating comfort-focused approaches with energy efficiency initiatives to foster sustainable and liveable environments for future generations. Today, ISO 7730 [3] and ASHRAE 55 [4] standards are widely utilized to assess indoor environments using indices such as PMV (Predicted Mean Vote) and PPD (Predicted Percentage of Dissatisfied). According to ASHRAE (2013), thermal sensation refers to the immediate sensory perception of the environment by occupants. Thermal preference indicates the desired ideal thermal conditions of occupants, while thermal acceptability measures the level of satisfaction with the thermal environment. Human responses to thermal comfort are generally categorized into three main concepts: thermal sensation, thermal preference, and thermal acceptability. While thermal sensation is objective and based on physiological measures, thermal comfort is subjective, reflecting individual perceptions and preferences [5-6]

The literature identifies six fundamental factors influencing a person's thermal comfort, categorized into four physical parameters and two individual variables. These factors include air temperature, air flow rate, relative humidity, mean radiant temperature, clothing insulation, and metabolic rate (activity level) [7]. These variables collectively contribute to how individuals perceive and experience comfort in indoor environments, highlighting the complex interplay between environmental conditions and personal preferences.

When literature examined; thermal comfort of employees in the Malaysian automotive industry was assessed at a critical manual assembly workstation. The research focused on operators stationed at the body assembly station. Various thermal comfort parameters were measured, and Predicted Mean Vote (PMV) and Predicted Percentage of Dissatisfied (PPD) values were calculated. PMV results ranged between 1.8 and 2.3, while PPD ranged from 60% to 84%. According to survey results, employees were notably affected by temperature, with heavy work clothes exacerbating their perception of warmth [8]. In a study conducted in primary school classes, an activity level of 1.2 met was determined and a difference of 0.2–0.4 clo was observed in the clothing insulation factors of girls and boys in the same class when the environment was heated and when it was not heated. It was determined that this difference was important for thermal comfort because it played an active role in the activation of the heat exchange systems in the body and that it caused different thermal conditions to be desired within the same class [9]. Thermal comfort models based on field studies use PMV-PPD indices to explain the differences between the predicted thermal sensation and the actual thermal sensation in indoor climate by taking into account human adaptation [10]. Discrepancies between PMV-PPD estimates and subjective estimates cover various aspects such as adaptive comfort model, air conditioning, habit, expectation, cultural difference, behavioral adaptation and the presence of environmental control [11]. Several factors contribute to the observed discrepancies in thermal comfort studies. These include methodological variations and study limitations such as differences in sampling protocols, sensor accuracy, clothing choices, and estimations of metabolic rates. Additionally, individual differences in thermal preferences and expectations play a significant role. Despite these sources of error, recent research suggests that the primary driver behind reported discrepancies in thermal comfort studies is the process of adaptation. This phenomenon is influenced by various environmental factors such as ventilation strategies, building designs, and climatic conditions [12]. Studies indicate that the PMV-PPD (Predicted Mean Vote - Predicted Percentage of Dissatisfied) model performs more accurately in air-conditioned environments compared to naturally ventilated buildings. Similar findings have been observed in mixed-mode buildings that operate with both air-conditioned and free-running strategies [13].

Ensuring workers feel comfortable with the temperature in industrial buildings is very important for their productivity and well-being. This involves efficiently using heating, ventilation, and air conditioning (HVAC) systems. Regular monitoring and improvements are needed to keep work areas at comfortable temperatures. This study aimed to assess the environmental conditions of a facility situated in Bolu province, specifically concerning its workforce. Measurements and surveys were carried out during three distinct seasons: summer, winter, and spring to obtain comprehensive data. The evaluation considered various factors, including the workers' age and gender, as well as their clothing choices and activity levels. The results revealed that workers' thermal comfort was primarily influenced by their physical activity levels and clothing type. Interestingly, age and gender did not impact the workers' thermal comfort status significantly. This suggests that, while individual characteristics are often considered important, the immediate environmental conditions and the workers' responses to them play a more critical role in ensuring comfort within the facility. Overall, the findings underscore the importance of considering activity levels and appropriate clothing when evaluating thermal comfort in workplace environments. They also indicate that age and gender may not be as crucial in this context.

2. METHODOLOGY

2.1. Location and Climate

Geographic features such as latitude, longitude, and altitude are tools used to define a location on Earth. Climatic features such as solar radiation, air flow, temperature, and humidity determine the indoor conditions of the building. Table 1 shows the climate features of Bolu province, where the industrial facility where the field study was conducted is located, according to the statistical data of the General Directorate of Meteorology.

Table 1. Climate characteristics of Bolu province (1920-2023)

Months / Parameter	1	2	3	4	5	6	7	8	9	10	11	12	Yearly
Average Temperature (°C)	0,5	1,8	4,7	9,6	14,1	17,3	19,8	20	16,2	11,8	6,9	2,8	10,5
Average Highest Temperature (°C)	5,3	7,2	11	16,6	21,4	24,6	27,4	28	24,3	19,3	13,3	7,5	17,2
Average Lowest Temperature (°C)	-3,5	-2,6	-0,5	3,6	7,6	10,4	12,4	12,7	9,5	6,2	2,1	-1,1	4,7
Average Sunshine Duration (hours)	2	2,9	4	5,3	6,7	8	8,9	8,7	6,9	4,8	3,4	2,1	5,3
Average Number of Rainy Days	15,5	14,4	14,7	13,4	14	11,9	6,16	5,19	7,17	10,6	11,8	14,7	139.7
Average Monthly Total Rainfall (mm)	57,7	48,7	50,9	50,8	60,4	59,9	28,3	24,7	28,3	41	45,9	58,8	555.4

2.2. Data Collection

The company designs, analyses, and manufactures moulds and has many years of experience in sheet metal moulds, including progressive moulds, transfer moulds, and deep drawing moulds for the automotive, white goods, and heating-cooling sectors. Thanks to its qualified workers and wide CNC machine park, the company provides service to its domestic and international customers (Figure 1).

Figure 1. The manufacturing process of the factory

Figure 2. A view of the factory during measurement and Testo-480 analyser

Thermal comfort categories have been determined in the ISO 7730 [3] standard by taking PMV and PPD parameters as reference (Figure 2). Testo 480's temperature measuring range is −15 to + 75 °C and 0–100 % RH, and the accuracy is ± 0.5 °C ± (1 0 % RH + 0 7 %). The globe temperature probe measuring range is 0 to + 120 °C, and accuracy is ± 0.3 °C. The air velocity probe measuring range is 0 to +5m/s. In indoor environments, the feeling of comfort is described with a PMV value of 0 or close to 0, a PPD value close to 0% as a percentage of dissatisfaction, and the state of discomfort is desired to be at the lowest level. Acceptable value ranges for categorised thermal comfort are given in Table 2, and the mathematical models of PMV and PPD values developed by Fanger are given in Equations 1 to 5. The study categorised the thermal comfort status as B, according to Table 2. While Group A has difficult environmental conditions, Group C is not recommended for areas where individuals spend long periods.

Table 2. Thermal comfort categories according to ISO 7730

Level	PPD (%)	PMV
Category A	<6	-0,2<PMV<+0,2
Category B	<10	-0,5<PMV<+0,5
Category C	<15	-0,7<PMV<+0,7

$$\begin{aligned} \mathrm{PMV} = {} & [0{,}303 * \exp(-0{,}036 * \mathrm{M}) + 0{,}028] * [(\mathrm{M}-\mathrm{W}) - 3{,}0 * 10^{-3}] \\ & * [5733 - 6{,}99 * (\mathrm{M}-\mathrm{W}) - \mathrm{p_a}] - 0{,}42[(\mathrm{M}-\mathrm{W}) - 58{,}15] - 1{,}7 * 10^{-5} \\ & * \mathrm{M} * (5867 - \mathrm{p_a}) - 0{,}0014 * \mathrm{M} * (34 - \mathrm{t_a}) - 3{,}96 * 10^{-8} * \mathrm{f_{cl}} \\ & * [(\mathrm{t_{cl}} + 273)^4 - (\bar{\mathrm{t}}_\mathrm{r} + 273)^4] - \mathrm{f_{cl}} * \mathrm{h_c} * (\mathrm{t_{cl}} - \mathrm{t_a}) \end{aligned} \tag{1}$$

$$\begin{aligned} \mathrm{t_{cl}} = {} & 35{,}7 - 0{,}028 * (\mathrm{M}-\mathrm{W}) - \mathrm{I_{cl}} * \{3{,}96 * 10^{-8} * \mathrm{f_{cl}} * [(\mathrm{t_{cl}} + 273)^4 - (\bar{\mathrm{t}}_\mathrm{r} + 273)^4] \\ & + \mathrm{f_{cl}} * \mathrm{h_c} * (\mathrm{t_{cl}} - \mathrm{t_a})\} \end{aligned} \tag{2}$$

$$\mathrm{h_c} = \begin{cases} 2{,}38 * |\mathrm{t_{cl}} - \mathrm{t_a}|^{0{,}25}, & 2{,}38 * |\mathrm{t_{cl}} - \mathrm{t_a}|^{0{,}25} > 12{,}1 * \sqrt{\mathrm{v_{ar}}} \\ 12{,}1 * \sqrt{\mathrm{v_{ar}}}, & 2{,}38 * |\mathrm{t_{cl}} - \mathrm{t_a}|^{0{,}25} < 12{,}1 * \sqrt{\mathrm{v_{ar}}} \end{cases} \tag{3}$$

$$\mathrm{f_{cl}} = \begin{cases} 1{,}00 + 1{,}290 * \mathrm{l_{cl}}, & \mathrm{l_{cl}} \le 0{,}078\ \mathrm{m^2} * \mathrm{K/W} \\ 1{,}05 + 0{,}645 * \mathrm{l_{cl}}, & \mathrm{l_{cl}} > 0{,}078\ \mathrm{m^2} * \mathrm{K/W} \end{cases} \tag{4}$$

$$PPD = 100 - 95 * exp(-0{,}03353 * PMV^4 - 0{,}2179 * PMV^2) \tag{5}$$

During the summer, personnel are specified to have a clothing thermal resistance of 1.2 clo, with their metabolic rates set at two met depending on their specific job tasks. Personnel working in quality control, design, and management offices are assigned a lower clothing thermal resistance of 1.0 clo, and their metabolic rates are adjusted to 1.5 met for activities such as reading, writing, drawing, and filing.

In the autumn, winter, and spring periods, personnel in the manufacturing sector are provided with a clothing thermal resistance of 1.5 clo while maintaining a metabolic rate of 2 met relevant to tasks performed. Similarly, personnel in quality control, design, and management offices are assigned a clothing thermal resistance of 1.2 clo, with their metabolic rates adjusted to 1.5 met for their respective duties. Based on these values, the PMV and PPD values were calculated.

2.3. Survey Design

A survey was conducted among workers engaged in machining activities within a factory setting to assess thermal comfort conditions using Fanger's 7-point scale (Table 3). The survey analysed responses to questions regarding how workers perceived the current temperature of their working environment and whether they found these conditions acceptable. Three main parts comprised the survey:

The first part gathered demographic data, including age, gender, and health status of the workers. The second part focused on the workers' clothing, the presence of heating or cooling devices in the environment, duration of exposure to the environment, and recent job tasks performed. The third part addressed subjective feelings about the thermal environment, preferences for thermal conditions, satisfaction with current comfort levels, lighting adequacy, and airflow presence. Questions were formulated based on guidelines from the ASHRAE-55 Standard [4], and surveys were administered through face-to-face interviews conducted during regular working hours.

Of the 202 measurements conducted, 51 were undertaken during the summer period, 52 in autumn, 54 in winter, and 45 in spring. The results were analysed separately for heating, cooling, and transition periods. The measurement protocol commenced 8 minutes after positioning the device in the measurement area, allowing sufficient time for stabilisation. Measurements were then taken continuously for 20 minutes using the stabilised device, and the results were recorded accordingly.

Table 3. Thermal perception scales used in the survey study

Thermal perception scales	Thermal comfort feeling	Thermal comfort preferences	Air circulation	Air circulation preferences	Thermal acceptability status
+3	Too hot	-	Too high	-	Unacceptable
+2	Hot	Cooler	High	Much more circulation	Unacceptable
+1	Slightly hot	Less cool	Slightly high	More circulation	Acceptable
0	Comfortable	Comfortable	Comfortable	Comfortable	Acceptable
-1	Slightly cold	Less hot	Slightly low	Low circulation	Acceptable
-2	Cold	Hotter	Low	Less circulation	Unacceptable
-3	Too cold	-	Too low	-	Unacceptable

2.4. Reliability Analysis

Cronbach's alpha coefficient is a well-established measure used to evaluate the reliability of survey items, influenced by factors like the length of the test and its dimensionality. This coefficient ranges from 0 to 1, with higher values signifying increased reliability. As a result, the scale and questions employed in this study were considered reliable, confirming their effectiveness in measuring the intended concepts. This reliability bolsters the validity of the findings and supports the use of the developed scale in subsequent research. The Cronbach alpha coefficient is calculated as the average weighted standard change, derived by dividing the total variances of the survey items by the overall variance. It assesses whether the items within the scale are homogeneous. A high Cronbach alpha indicates that the survey questions share similar characteristics and effectively capture the same constructs. Since Cronbach alpha is computed based on all questions using a consistent statistical method, it is the most reliable indicator of overall scale reliability compared to other coefficients [14]. When literature studies are examined, reliability values in fit index models are accepted between 0.70 and 0.90 [15-16]. Cronbach alpha values of the survey scales applied in the factory worksite were examined in detail.

3. RESULTS AND DISCUSSIONS

When literature studies are examined, reliability values in fit index models are accepted between 0.70 and 0.90 [15]. Cronbach alpha value of the surveys applied in the factory work area was found to be 0.732, standardised Cronbach alpha value was found to be 0.779, and it was seen that the questions and scales were reliable for analysis. The Chi-Square Test was used to analyze thermal comfort differences based on the gender, activity, age, and clothing status of the workers, and the results are shown in Table 4. In the Chi-Square test, thermal sensations and thermal comfort votes significantly differed. SPSS 27.0 statistical software was used to analyse the correlations between variables and thermal satisfaction.

User satisfaction variables were structured into groups by factor analysis with Oblimin Rotation, which assumes the factors are related. Pearson Chi-Square test was applied to determine whether the frequency distributions of two or more variables between different groups contained significant differences [17]. When the heating, cooling and transition periods (autumn and spring) were evaluated considering the gender difference, the chi-square value was calculated as 10.870, and the significance level was 0.054. It was seen that there was no difference between the groups for a significance level greater than 0.05. Therefore, the gender difference did not affect thermal comfort. When the heating, cooling and transition periods (autumn and spring) were evaluated considering the activity level (those who design, model, test and measure in the office had a metabolic rate of 1.5, those who constantly work standing at the machine in the machining process had a metabolic rate of 2.0), the chi-square value was calculated as 16.189 and the significance level was calculated as 0.006. For a significance level less than 0.05, it was seen that there was a difference between the groups, and therefore, the activity difference had an effect on thermal comfort. When the heating, cooling and transition periods (autumn and spring) were evaluated considering the age difference (under 30 years old, including 30 years old and over 30 years old), the chi-square value was calculated as 2.754, and the significance level was calculated as 0.738. For a significance level greater than 0.05, it was seen that there was no significant difference between the groups, and therefore, the age difference had no effect on thermal comfort. When the heating, cooling and transition periods (autumn and spring) were evaluated considering the difference in clothing status (1.2 clo for those who do design, modelling, testing and measurement in the office), 1.5 clo for those who work at the machine in the machining process), the chi-square value was calculated as 17.605. The significance level was calculated as 0.003. For a significance level less than 0.05, it was seen that there was a significant difference between the groups, and therefore, the clothing difference had an effect on thermal comfort.

Table 4. Pearson Chi-Square tests

Parameter		Period	Thermal comfort							Total	Pearson Chi-Square (ki-kare)	Level of Significance
			Too cold	Cold	Slightly cold	Comfort	Slightly hot	Hot	Too hot			
			(-3)	(-2)	(-1)	0	(+1)	(+2)	(+3)			
Gender	Male	Summer Period	0	0	0	3	3	9	24	39	10,870[a]	0,054
		Winter Period	0	0	5	17	18	3	0	43		
		Autumn Period	0	1	3	9	16	11	1	41		
		Spring Period	0	0	3	17	6	4	1	31		
	Female	Summer Period	0	0	0	1	1	5	5	12		
		Winter Period	0	0	1	2	5	3	0	11		
		Autumn Period	0	0	0	3	6	2	0	11		
		Spring Period	0	0	0	3	3	7	1	14		
Total			0	1	12	55	58	44	32	202		
Metabolic rate	met 1,5	Summer Period	0	0	0	3	3	2	0	8	16,189[b]	0,006
		Winter Period	0	0	0	7	2	2	2	13		
		Autumn Period	0	0	1	4	2	1	0	8		
		Spring Period	0	0	2	7	1	2	0	12		
	met 2,0	Summer Period	0	0	0	1	1	12	29	43		
		Winter Period	0	0	6	12	21	2	0	41		
		Autumn Period	0	1	2	8	20	13	0	44		
		Spring Period	0	0	1	13	9	9	1	33		

Total			0	1	12	55	59	43	32	202		
Age	**<30**	**Summer Period**	0	0	0	2	2	5	14	23	2,754[c]	0,738
		Winter Period	0	0	3	9	10	2	0	24		
		Autumn Period	0	0	1	5	12	5	1	24		
		Spring Period	0	0	2	6	3	6	2	19		
	≥30	**Summer Period**	0	0	0	2	2	9	15	28		
		Winter Period	0	0	3	10	13	3	1	30		
		Autumn Period	0	1	2	7	10	8	0	28		
		Spring Period	0	0	1	14	6	5	0	26		
Total			0	1	12	55	58	43	33	202		
Clo	**1,2**	**Summer Period**	0	0	0	3	3	2	0	8	17,605[d]	0,003
		Winter Period	0	0	0	7	2	3	0	12		
		Autumn Period	0	0	1	4	2	1	0	8		
		Spring Period	0	0	2	7	2	1	0	12		
	1,5	**Summer Period**	0	0	0	1	1	12	29	43		
		Winter Period	0	0	6	12	22	2	0	42		
		Autumn Period	0	1	2	8	20	13	0	44		
		Spring Period	0	0	1	13	9	9	1	33		
Total			0	1	12	55	61	43	30	202		

a. 3 cells (25,0%) have expected count less than 5. The minimum expected count is ,24.
b. 3 cells (25,0%) have expected count less than 5. The minimum expected count is ,20.
c. 2 cells (16,7%) have expected count less than 5. The minimum expected count is ,45.
d. 3 cells (25,0%) have expected count less than 5. The minimum expected count is ,20.

Factors affecting thermal comfort, such as employee age, gender, type of work, and clothing status, were examined in detail for heating, cooling, and transition (spring and autumn) periods. Levene test tests the homogeneity of group variances among statistical analysis methods (Table 5). Only significant values are shown in the table. In the homogeneity of variances, the t-test and ANOVA test are used. Independent samples t-test is an analysis method that interprets whether there is a statistically significant difference between the mean scores for two groups.

Table 5. Comparison of activity level and clothing status for all periods using Levene's test and t-test.

	Variances	**Levene's Test**		**t-tests**							**Hypothesis Acceptance**
		F	**Sig.**	**t**	**df**	**Sig. (2-tailed)**	**Mean Differences**	**Error**	**95% confidence**		
									Lower Limit	**Lower Limit**	
Metabolic rates 1.5 and 2	Homogeneity	0,113	0,737	-2,785	200	0,006	-0,57173	0,20529	-0,97654	-0,16692	There is a significant difference, the null hypothesis is rejected.
	Non-Homogeneity			-2,868	64,36	0,006	-0,57173	0,19935	-0,96994	-0,17353	

Clo values 1.2 and 1.5	Homogeneity	0,028	0,868	-2,790	200	0,006	-0,57809	0,20718	-0,98663	-0,16954	There is a significant difference according to non-homogeneous variances, but the number of samples needs to be increased to verify the hypothesis.
	Non-Homogeneity			-2,849	61,32	0,006	-0,57809	0,20288	-0,98373	-0,17245	

The groups were grouped according to the heating, cooling and transition (spring and autumn) periods and the workers' answers in these periods were compared. The differences between the periods were revealed with this method. In this table, firstly, the p-value of the F value was examined, and in cases where p>0.05, the “Sig. (2-tailed)” part of the same column was examined to make a decision. When the “Sig. (2-tailed)” column was looked at, it was seen that there was a significant difference in cases where p<0.05 and the hypothesis was confirmed. For the activity level, there was a statistically significant difference with 95% confidence for all periods in the met 1.5 and met 2 cases. There was a significant difference according to non-homogeneous variances in the 1.2 clo and 1.5 clo clothing status case. There was no significant difference in gender between ≤30 years and >30 years. Activity level affects thermal comfort, and it is consistent with these results that workers who work standing at the machine and have medium-level limb movement perceive their environment as warmer.

Thermal comfort conditions according to different factors: The ANOVA test was applied for heating, cooling and transition (autumn and spring) periods. As a result of this test, an LSD (advanced level) test was performed to understand which group the difference was in for the differences detected, and the results were presented. LSD test was applied for all periods, and significance levels were determined. When the thermal perceptions of all workers were evaluated in the heating, cooling and transition (autumn and spring) periods, the cooling period data constituted a significant difference compared to all other periods.

When the workers' thermal perception and the estimated average vote values were compared for all periods, it was determined that the workers found the thermal environment acceptable due to their personal preferences in periods other than the cooling period. When the calculated PMV values were analysed, a significant difference was observed except for the heating and autumn periods. When the workers' thermal perception and the estimated average vote values were compared for all periods, it was determined that the workers found the thermal environment acceptable due to their personal preferences in periods other than the cooling period.

Table 6. The distribution of the estimated mean vote (PMV) of workers with Met 2 across periods.

Parameter (I)	Parameter (J)	Mean Difference (I-J)	Error	Significance Level	95% confidence	
					Lower Limit	Upper Limit
1,00 (Summer)	2,00	1,17543*	0,02682	0,000	1,1225	1,2284
	3,00	1,06815*	0,02635	0,000	1,0161	1,1202
	4,00	,84406*	0,02843	0,000	0,7879	0,9002
2,00 (Winter)	1,00	-1,17543*	0,02682	0,000	-1,2284	-1,1225
	3,00	-,10728*	0,02667	0,000	-0,1600	-0,0546
	4,00	-,33137*	0,02873	0,000	-0,3881	-0,2746
3,00 (Autumn)	1,00	-1,06815*	0,02635	0,000	-1,1202	-1,0161
	2,00	,10728*	0,02667	0,000	0,0546	0,1600
	4,00	-,22409*	0,02829	0,000	-0,2800	-0,1682
4,00 (Spring)	1,00	-,84406*	0,02843	0,000	-0,9002	-0,7879
	2,00	,33137*	0,02873	0,000	0,2746	0,3881
	3,00	,22409*	0,02829	0,000	0,1682	0,2800

When the heating, cooling and transition periods (autumn and spring) were evaluated by taking into account the difference in activity level (1.5 metabolic rates for those who do design, modelling, testing and measurement in the office, 2.0 metabolic rate (Table 6) for those who constantly stand at the machine in the machining process), it was seen that there was a significant difference except for the correlation between the heating period and the spring period. Therefore, the activity difference was effective in terms of thermal comfort (Table 7).

Table 7. The distribution of the estimated mean vote (PMV) of workers with Met 2 across periods.

Parameter (I)	Parameter (J)	Mean Difference (I-J)	Error	Significance Level	95% confidence	
					Lower Limit	Upper Limit
1,00 (Summer)	2,00	,60740*	0,17897	0,002	0,2448	0,9700
	3,00	1,28625*	0,19914	0,000	0,8828	1,6897
	4,00	,77958*	0,18179	0,000	0,4112	1,1479
2,00 (Winter)	1,00	-,60740*	0,17897	0,002	-0,9700	-0,2448
	3,00	,67885*	0,17897	0,001	0,3162	1,0415
	4,00	0,17218	0,15944	0,287	-0,1509	0,4952
3,00 (Autumn)	1,00	-1,28625*	0,19914	0,000	-1,6897	-0,8828
	2,00	-,67885*	0,17897	0,001	-1,0415	-0,3162
	4,00	-,50667*	0,18179	0,008	-0,8750	-0,1383
4,00 (Spring)	1,00	-,77958*	0,18179	0,000	-1,1479	-0,4112
	2,00	-0,17218	0,15944	0,287	-0,4952	0,1509
	3,00	,50667*	0,18179	0,008	0,1383	0,8750

When the heating, cooling and transition periods (autumn and spring) were evaluated by taking into account the difference in clothing conditions (1.2 clo for those doing design, modelling, testing and measurement in the office, 1.5 clo for those working at the machine in the machining process), the clothing conditions of office workers did not create a significant difference, while the clothing conditions of those working in machining create a significant difference (Table 8 and Table 9).

Tablo 8. Estimated mean vote (PMV) values of workers with a clo value of 1.2

Parameter (I)	Parameter (J)	Mean Difference (I-J)	Error	Significance Level	95% confidence Lower Limit	95% confidence Lower Limit
1,00 (Summer)	2,00	,58542*	0,18311	0,003	0,2141	0,9568
	3,00	1,28625*	0,20059	0,000	0,8794	1,6931
	4,00	,77958*	0,18311	0,000	0,4082	1,1509
2,00 (Winter)	1,00	-,58542*	0,18311	0,003	-0,9568	-0,2141
	3,00	,70083*	0,18311	0,000	0,3295	1,0722
	4,00	0,19417	0,16378	0,244	-0,1380	0,5263
3,00 (Autumn)	1,00	-1,28625*	0,20059	0,000	-1,6931	-0,8794
	2,00	-,70083*	0,18311	0,000	-1,0722	-0,3295
	4,00	-,50667*	0,18311	0,009	-0,8780	-0,1353
4,00 (Spring)	1,00	-,77958*	0,18311	0,000	-1,1509	-0,4082
	2,00	-0,19417	0,16378	0,244	-0,5263	0,1380
	3,00	,50667*	0,18311	0,009	0,1353	0,8780

Similar significant differences were observed in the evaluations made for the 1.5 clo value. The point to be noted here is that some protective equipment worn for safety reasons causes higher PMV values in terms of temperature in the summer period, which leads to dissatisfaction.

Tablo 9. Estimated mean vote (PMV) values of workers with a clo value of 1.5

Parameter (I)	Parameter (J)	Mean Difference (I-J)	Error	Significance Level	95% confidence Lower Limit	95% confidence Lower Limit
1,00 (Summer)	2,00	1,18122*	0,02689	0,000	1,1281	1,2343
	3,00	1,06815*	0,02658	0,000	1,0157	1,1206
	4,00	,84406*	0,02869	0,000	0,7874	0,9007
2,00 (Winter)	1,00	-1,18122*	0,02689	0,000	-1,2343	-1,1281
	3,00	-,11307*	0,02674	0,000	-0,1659	-0,0603
	4,00	-,33716*	0,02883	0,000	-0,3941	-0,2802
3,00 (Autumn)	1,00	-1,06815*	0,02658	0,000	-1,1206	-1,0157
	2,00	,11307*	0,02674	0,000	0,0603	0,1659
	4,00	-,22409*	0,02854	0,000	-0,2805	-0,1677
4,00 (Spring)	1,00	-,84406*	0,02869	0,000	-0,9007	-0,7874
	2,00	,33716*	0,02883	0,000	0,2802	0,3941
	3,00	,22409*	0,02854	0,000	0,1677	0,2805

4. CONCLUSIONS

This research focused on evaluating the thermal comfort conditions within the work area according to established standards, particularly emphasising the efficiency of environmental conditions for individuals working in the machining sector within the industry. In line with the data obtained from the factory field study,

Further analysis of the calculated PMV values revealed a significant difference, except for the heating and autumn periods. Despite this, workers' subjective thermal perceptions consistently aligned with their overall acceptance of the thermal conditions, indicating that personal preferences played a crucial role in determining their comfort levels.

In summary, workers' subjective feelings about the thermal environment corresponded well with the estimated PMV values, confirming that their acceptance of thermal conditions was influenced by their preferences, particularly during periods other than cooling.

When the heating, cooling and transition periods (autumn and spring) were evaluated based on gender status, no significant difference was observed.

There is no significant difference between gender and age ≤30 and age >30. Activity level affects thermal comfort, and it is consistent with these results that workers who work standing at the machine and have medium-level limb movements perceive the environment they are in as warmer. The evaluation indicated a significant difference in thermal comfort influenced by activity levels, except for the correlation between the heating and spring periods. This suggests that the higher metabolic rate associated with machining tasks had a notable effect on thermal comfort perception across different seasonal conditions, highlighting the importance of considering activity levels when assessing and managing thermal comfort in industrial environments.

The analysis revealed that office workers' clothing conditions did not significantly affect thermal comfort across the evaluated periods. However, the higher clothing insulation (1.5 clo) did have a noticeable impact on thermal comfort for workers engaged in machining processes. This suggests that the type of clothing worn by machining workers played a more crucial role in their thermal comfort perception compared to office workers, particularly during transitions between different seasons and temperature conditions.

The study offers valuable insights into the alignment between PMV (Predicted Mean Vote) values and workers' subjective perceptions of thermal comfort, but further exploration of practical implications is needed. Industries could benefit from training programs that guide employees on appropriate clothing choices based on seasonal changes and activity levels, emphasising the importance of clothing insulation for comfort. Additionally, establishing guidelines for modifying environmental conditions, such as adjusting HVAC systems, would be beneficial. Recognising the influence of activity levels on thermal comfort opens opportunities for ergonomic workspace designs. Further research on the insulation properties of different clothing types could provide actionable recommendations. Sharing these insights with industry stakeholders can lead to more effective policies that enhance thermal comfort, worker satisfaction, and productivity. Integrating these findings into practice will significantly improve their relevance in industrial settings.

Understanding the specific insulation properties of different types of clothing can guide workers in making informed choices that optimise their comfort based on their activity levels and the environmental conditions they face. For instance, thicker, insulated fabrics may be more appropriate during colder months, while lighter materials might be better suited for warmer conditions. Moreover, industries could benefit from developing guidelines that recommend appropriate clothing based on the anticipated thermal conditions for each season. This could include creating educational materials or workshops to help employees select the right clothing for their roles. Incorporating insights into how clothing insulation interacts with workplace temperature and humidity levels would also help employers create a more comfortable work environment. Ultimately, these recommendations would support better thermal management practices and improve worker satisfaction and productivity.

NOMENCLATURE

clo	Clothing insulation ($m^2.K/W$)
I_{cl}	clothing insulation in square meters kelvin per watt ($m^2.K/W$)
M	Metabolic rate (W/m^2)
met	Activity level, met, (W/m^2)
PMV	Predicted Mean Vote
PPD	Predicted Percentage of Dissatisfied
RH	Relative humidity (%)
T_a	Indoor air temperature (°C)

$t_{a,l}$	Outdoor air temperature (ºC)
t_{cl}	Clothing surface temperature (ºC)
V_{ar}	Air velocity (m/s)
f_{cl}	Clothing surface factor
h_c	Heat transfer coefficient (W/(m².K))
T_r	Radiant temperature (°C)
T_g	Globe temperature (ºC)

DECLARATION OF ETHICAL STANDARDS

The authors of the paper submitted declare that nothing which is necessary for achieving the paper requires ethical committee and/or legal-special permissions.

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CONFLICT OF INTEREST

There is no conflict of interest in this study.

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