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THERMAL COMFORT ANALYSIS OF WORKERS IN AN INDUSTRIAL FACILITY: A FIELD STUDY IN BOLU PROVINCE

İsmail CANER [*]
Şükran ÖZBAĞ [**]
Nadir İLTEN [***]

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Abstract: Thermal comfort in industrial facilities has critical importance in terms of worker productivity and health. Providing optimal thermal comfort requires effective use of HVAC systems. In this context, continuous monitoring and improvement are important to ensure appropriate thermal conditions in the working environment. In this study, the current environmental conditions of a facility located in Bolu province were evaluated in terms of workers with the help of measurements and surveys. The measurements were taken separately for summer, winter and spring periods and the evaluations were made by taking into account age, gender, clothing status and activity status. PMV and PPD values were calculated and these values were compared with the survey results and the current thermal comfort conditions were revealed. As a result, it was seen that the clothing status could cause a change between 0.9 ºC and 2.2 ºC in the optimum working temperature.

Keywords: Thermal Comfort, Industrial Facility, Survey, PMV-PPD

Endüstriyel Tesiste Çalışanların Termal Konfor Analizi: Bolu İli Saha Çalışması

Öz: Endüstriyel tesislerde termal konfor, işçi verimliliği ve sağlık açısından kritik öneme sahiptir. Optimal termal konfor sağlanması, HVAC sistemlerinin etkin kullanımını gerektirir. Bu bağlamda, çalışma ortamında uygun termal koşulların sağlanması için sürekli izleme ve iyileştirme önemlidir. Bu çalışmada Bolu ilinde bulunan bir tesisin mevcut ortam koşulları ölçüm ve anket yardımı ile işçiler açısından değerlendirilmiştir. Ölçümler yaz, kış ve bahar dönemleri olmak üzere ayrı ayrı ele alınmış ve yaş, cinsiyet, kıyafet durumu ve aktivite durumları dikkate alınarak değerlendirmeler yapılmıştır. PMV, PPD değerleri hesaplanmış ve bu değerler yapılan anket sonuçları ile kıyaslanarak mevcut ısıl konfor koşulları ortaya konulmuştur. Sonuç olarak kıyafet durumunun optimum çalışma sıcaklığında 0,9 ºC ile 2,2 ºC arasında değişime neden olabileceği görülmüştür.

Anahtar Kelimeler: Termal Konfor, Endüstriyel Tesis, Anket, PMV-PPD

[*,**,***] Balikesir University, Department of Mechanical Engineering, 10145, Balikesir, Turkiye

Corresponding author: ismail@balikesir.edu.tr

1. INTRODUCTION

Today, a substantial amount of energy consumed in both developed and developing countries is attributed to heating and cooling buildings. Given the constraints of finite energy resources and the environmental consequences of excessive consumption, enhancing energy efficiency in buildings is crucial for sustainable development. Understanding the thermal comfort of occupants is essential for devising effective strategies to reduce energy consumption associated with heating and cooling systems. It is imperative that energy savings do not compromise the comfort and productivity of building occupants. (Omidvar and Kim, 2020). With the development of technology and the gradual improvement of people's living standards, comfort in living spaces has become increasingly important (Wu et al., 2020). According to the research of Arif et al. (2016), people spend approximately 80-90% of their lives in indoor environments. The past fifty years have seen substantial industrialization and urbanization, resulting in a notable shift from outdoor to indoor working environments, such as office buildings or factories. Creating an efficient and conducive working environment is essential and fundamental for optimizing worker performance effectiveness (Lan et al., 2011).

Since the 1970s, various thermal comfort models have been developed to estimate the thermal sensation of people in indoor environments. In this context, two types of thermal comfort approaches have been intensively studied and discussed by researchers. The most widely used is the PMV-PPD (Predicted Mean Vote - Predicted Percent Dissatisfied) model developed by Fanger and Toftum (2002). The PMV and the percentage of thermally dissatisfied people (PPD) indices developed by Fanger, which estimate the average value of the thermal votes of a group of people, are used worldwide to estimate and evaluate indoor thermal comfort in buildings (Zhang et al., 2020). According to Fanger, the main reason for creating thermal comfort is to meet people's desire to feel comfortable in thermal terms. The PMV index reflects the average thermal sensation experienced by a group of individuals who are exposed to the same environmental conditions, engaged in the same activity, and wearing the same level of clothing insulation. The PPD indicator is the value that reveals the rate of people's dissatisfaction with the thermal environment (Fanger and Toftum, 2002).

Today, ISO 7730 (1995) and ASHRAE 55 (2013) standards are commonly used to assess indoor environments using PMV (Predicted Mean Vote) and PPD (Predicted Percentage of Dissatisfied) indices. ASHRAE (2013) defines thermal sensation as the immediate sensory perception of the environment by occupants. Thermal preference refers to the ideal thermal conditions desired by occupants, while thermal acceptability denotes the level of satisfaction with the thermal environment. Human responses to thermal comfort are typically categorized into three concepts: thermal sensation, thermal preference, and thermal acceptability. While thermal sensation is objective, based on physiological measures, thermal comfort is subjective, reflecting individual perceptions and preferences (Langevin et al., 2013; Langevin et al., 2015). Six basic factors affecting a person's thermal comfort are summarized in the literature, four physical parameters and two individual variables. These factors are air temperature, air flow rate, relative humidity, average ambient temperature, clothing insulation and metabolic rate, i.e. activity level (Enescu, 2017; Akan and Ünal, 2021).

Research shows that temperature is very important for user productivity (Ünal, 2021). Different reactions have been observed in the productivity of building occupants in temperatures ranging from 18 ºC to 30 ºC. It is seen that the most suitable temperature range in terms of comfort in an office environment is 21 ºC –25 ºC. If the temperature rises above 25 ºC, it has been recorded that there is a 2% decrease in productivity for every 1 ºC up to 30 ºC (Kekol et al., 2010). As a result of the thermal comfort study conducted in a factory producing steel products in Brazil, it is shown that high temperatures are dominant in the examined environments and that this can affect individual production performance and cause health problems that can lead to serious work accidents. In 73.62% of the measurements, the thermal perceptions of the workers were reported as slightly hot, hot and very hot. The sensations reported to be incompatible with the PMV Model were evaluated as being due to differential scales, considering that the thermal sensation rating obtained from the survey was under a scale with a combined variation, while the PMV evaluated between -3 and +3 had a continuous variation. The results of the study emphasize that there may be major errors in the use of international metabolic rate values and that the study should be conducted according to the characteristics of the Brazilian ethnic population (de Melo Pinto et al., 2015). A study on adaptive thermal comfort was conducted among workers in a mini-industrial unit located in a tropical region of India, covering both summer and winter seasons. The average comfort temperature was found to be 32.2 ºC, with significant seasonal variations: more than 9.5 ºC difference between winter and summer comfort temperatures. Additionally, the seasonally preferred temperature differed by over 7.9 ºC at the study location. On average, the preferred temperature was approximately 2.5 ºC lower than the comfort temperature. The study highlighted that the factory workers exhibited high thermal adaptation, influenced by behavioral adjustments and increased air movement (Kumar et al., 2021).

Several studies conducted during the investigation of job performance have shown that women's job performance is little sensitive to indoor environments than men. It was found that when the indoor temperature was 28 ºC compared to a moderate environment, the reaction speed of women in doing work was not affected, while the performance of men in the same task decreased significantly (Wyon et al., 1979). The PMV value of a travertine processing plant was calculated as 11.24% with a PMV value of -0.5. The PPD rate was 32.47% at a PMV value of -1.12. The dissatisfaction rate increased by approximately 3 times when the difference in PMV value was 124%. This study has revealed the importance of PPD to fully understand the thermal comfort of workers and the PPD result of 32.47% has shown that almost one third of the workers do not find the working environment suitable. It has been assessed that an inadequate thermal environment can diminish worker performance, leading to decreased productivity and potentially negative impacts on the company's sales figures. Ensuring suitable work clothes and maintaining specific values of temperature, humidity, and air flow rate through proper ventilation systems are crucial for maintaining optimal thermal comfort levels among workers (Aritan, 2019).

Ensuring ideal temperature and humidity values in the work environment is of great importance in terms of worker performance and has a direct effect on motivation, work concentration and productivity. In order to ensure both worker health and continuity of worker performance in summer and winter conditions, thermal comfort must be provided with a correct air conditioning system. Since the perception, task performance and reaction speeds of people working in environments that affect human health (hot, cold, humid, high air flow, etc.) are impaired, the probability of low performance or making mistakes increases. For example; workers may tend to escape from the environment in extremely hot or extremely cold environments, they may risk a work accident by not wearing appropriate protective clothing in hot environments, their ability to concentrate on work may begin to decrease and the risk of errors in the work performed may increase (Caner, 2020; Özbağ, 2024)).

Studies on thermal comfort conditions are frequently encountered in the literature. However, studies on industrial thermal comfort conditions are very limited both nationally and internationally. Research on the work field primarily includes office environments, schools and hospital environments. This study aims to compare thermal comfort parameters necessary for industrial workers based on their activities with data collected from the field against theoretical values defined in reference standards. Additionally, it seeks to experimentally examine how activity levels during machining and the insulation provided by workwear impact thermal comfort and work performance. The goal is to evaluate field data concerning the work environment and emphasize the need to optimize thermal comfort components through HVAC systems. The necessary ethical approval document and permissions for the survey and measurements applied in the study were obtained from the company. We obtained the necessary ethical approval and permissions from the company for conducting the survey and measurements used in the study.

2. METHODOLOGY

2.1. General Characteristics of The Company

Yeni Öztürk Kalıp Makine San. Tic.Ltd.Şti., where field work is carried out, is structured in a 10,000 m² closed area at 40.74 latitude and 31.73 longitude in the Susuzkınık Organized Industrial Zone of Bolu province.

Figure 1:
General view of the industrial facility

Since 1983, the company has been offering its manufacturing capabilities in metal molding, CNC processing and sheet metal forming for the automotive, medical, heating & cooling, electronics and white goods sectors with 84 blue-collar and 17 engineer workers.

Figure 2:
General view of the research area

2.2. Thermal Comfort Assessment and Survey

The analytical method that forms the basis of the thermal balance equation between the user and the environment, which Fanger obtained as a result of experimental studies, is known as the PMV (Predicted Mean Vote) Model or Static Model. The comfort status of an environment can be determined with this model. The thermal perceptions of users in the environment they are in can be revealed by evaluating the PMV calculated with the 7-point thermal sensation scale (ISO 7730, 1995). In order to estimate the people who feel uncomfortable in the same environment, the Predicted Percentage of Dissatisfaction (PPD) can be calculated based on the PMV value (Figure 3).

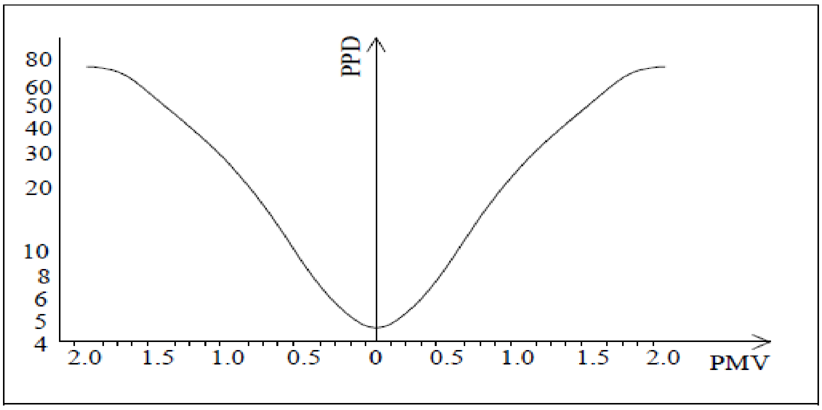

Figure 3:
PMV-PPD chart

A survey was conducted on workers performing the machining process activities in the factory area by evaluating thermal comfort conditions in line with Fanger's 7-scale scale. Ashrae sensation scale were used in the study. The answers to the questions 'How do you currently define the temperature of the working environment?' and 'Are the working environment conditions currently at an acceptable level?' were analyzed and thermal comfort conditions were determined. The application survey consists of three parts; In the first part; information was asked about the worker's age, gender, and whether he/she has any health problems. In the second part; the worker's clothing status, whether there are devices that affect heating and cooling in the working environment, how long he/she has been in the working environment, and the types of work he/she has done in the last hour were asked. In the third part; questions were asked about the worker's feeling in the thermal environment, how he/she wants the working environment to be in terms of thermal conditions, whether the comfort conditions in the environment are acceptable, the adequacy of the lighting level, and the amount of breeze in the environment. The questions were created by taking the ASHRAE-55 Standard [7] as reference. The surveys, prepared as recommended by the standards, were applied to individuals by face-to-face interviews during routine working hours.

Table 1: Thermal sensation scale

	Too cold	Cold	Little cold	Neutral	Sligtly warm	Hot	Too hot
Bedford	1	2	3	4	5	6	7
Ashrae	-3	-2	-1	0	+1	+2	+3

For metabolic rates and clothing insulation depending on the activity level of workers, the values specified in ISO 7730 were taken as reference. In summer period measurements; clothing thermal resistance was accepted as 1.2 clo for personnel using work clothes and personal protective equipment within the framework of occupational safety in the manufacturing field and metabolic rates of personnel working in machines requiring intensive limb movement according to the type of work they do were accepted as 2 met, clothing thermal resistance was accepted as 1.0 clo for personnel working in quality control, design and management offices and metabolic rates of personnel reading, writing, drawing and filing according to the type of work they do were accepted as 1.5 met, in autumn, winter and spring period measurements; clothing thermal resistance was accepted as 1.5 clo for personnel using work clothes and personal protective equipment within the framework of occupational safety in the manufacturing field and metabolic rates of personnel working in machines requiring intensive limb movement according to the type of work they do were accepted as 2 met, clothing thermal resistance was accepted as 1.2 clo for personnel working in quality control, design and management offices and metabolic rates of personnel reading, writing, drawing and filing according to the type of work they do were accepted as 1.5 met. By evaluating the survey results, the actual satisfaction rate felt by the users (AMV) and the actual dissatisfaction percentage (APD) were calculated according to the scale given in Table 1.

Table 2: Properties of Testo 480 device

Measurement Probe	Measurement range	Tolerence	
Indoor Temperature	-20 to +70 °C	±0,5 °C	
Relative Humidity	0 to 100 %RH	±(1,0 %RH + 0,7%) ±(1,4 %RH + 0,7%)	0 to 90 %RH 90 to 100 %RH
Globe Temperature Ø 150 mm	0 to +120 °C	±0,3 °C	
Air velocity	0 to +50 °C 0 to +5 m/s +700 to +1100 hPa	±0,5 °C ±(0,03 m/s +4%) ±3 hPa	

In order to calculate PMV and PPD values, indoor thermal comfort parameters consisting of indoor air temperature, relative humidity, sphere temperature and air flow velocity were measured with Testo-480 (Figure 4) device. There are three different probes in the device. The first of the probes measures temperature and relative humidity, the second measures sphere temperature and the third measures air flow velocity. The measurement range and sensitivity values of the probes of the device are given in Table 2. During the measurement, the device was positioned in the middle of the measurement area and at a height of 110 cm as required in ASHRAE-55 (2013). Of the 202 measurements made, 51 were made in the summer period, 52 in the autumn period, 54 in the winter period and 45 in the spring period. The results were evaluated separately for heating, cooling and transition periods. The measurement process was started 8 minutes after the device was placed in the measurement area and it was considered that the device became stable. Measurements were made for 20 minutes with the device that became stable and recorded.

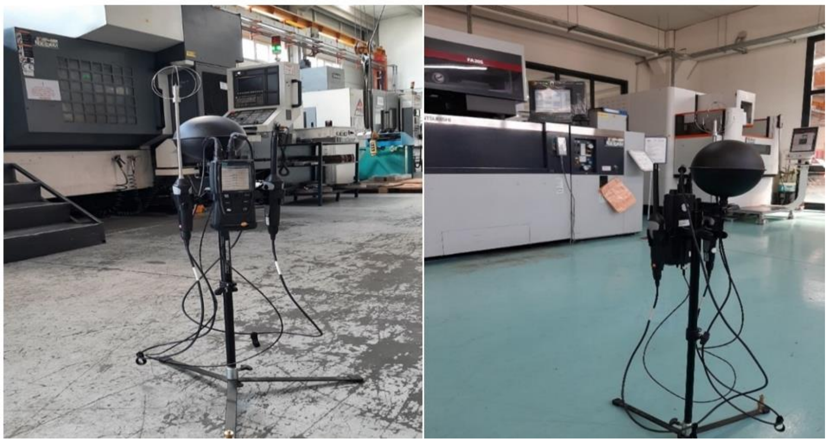

Figure 4:
General view of Testo-480 at the time of measurement

3. RESULTS AND DISCUSSIONS

3.1. Analysis of thermal comfort parameters

The analyses of thermal comfort parameters for heating, cooling and transition periods are given in Table 3. During the heating period, the indoor temperature was measured as an average of 21.43 ºC, a minimum of 19.40 ºC and a maximum of 25.50 ºC. It was observed that the average temperature values of the heating period were within the reference values in ASHRAE-55 (2013) and ISO 7730 (1995) standards. During the cooling period, the indoor temperature was measured as an average of 28.57 ºC, a minimum of 25.40 ºC and a maximum of 29.50 ºC. The temperatures measured during the cooling period were outside the reference values in the standards.

For the heating period, measurements were made in February and the average outdoor air temperature during the measurement period was 1.2 ºC; for the cooling period, measurements were made in August and the average outdoor air temperature during the measurement period was 25.7 ºC; for the spring period, measurements were made in April and the average outdoor air temperature during the measurement period was 16.6 ºC; for the autumn period, measurements were made in November and the average outdoor air temperature during the measurement hours was 10 ºC. According to ASHRAE-55 (2013) standard, the relative humidity level should be between 30-60% and according to ISO 7730 (1995) standard, the relative humidity level should be between 30-70%. Average relative humidity values are within the standard reference value range in all recorded measurements. The highest air flow speed in the heating period was measured as 0.24 m/s, and the highest air flow speed in the cooling period was measured as 0.25 m/s. According to ASHRAE-55 standard, the air flow speed should be 0.16 m/s and according to ISO 7730 standard, the air flow speed should be 0.19 m/s. The measured values are well above the reference values in the standards. When the average values were checked, the average air flow speed for the heating period was found to be 0.14 m/s and 0.15 m/s for the cooling period. ISO 7730 standard defines the operative temperature as 22 ± 2 ºC in the cooling period and 24.5 ± 1.5 ºC in the heating period.

Table 3: Analysis of thermal comfort parameters according to periods.

Criteria	Minimum				Maksimum				Average			
	Summer	Winter	Autumn	Spring	Summer	Winter	Autumn	Spring	Summer	Winter	Autumn	Spring
Indoor temp. (ºC)	25,40	19,40	18,90	21,70	29,50	25,50	24,90	26,30	28,57	21,43	21,80	23,26
Relative Hum. (%)	39,30	33,10	37,20	34,70	72,70	43,10	44,50	49,90	58,72	37,34	39,67	44,56
Air velocity (m/s)	0,05	0,05	0,05	0,05	0,25	0,24	0,33	0,26	0,15	0,14	0,14	0,12
Average radiant temp. (ºC)	25,20	18,60	18,20	21,20	29,40	25,90	25,90	26,40	28,26	21,17	21,44	22,79
Operative temp. (ºC)	25,3	19,0	18,55	21,45	29,45	25,7	25,4	26,35	28,41	21,3	21,62	23,02
Outdoor air temp. (ºC)	23	-4	8	13	27,5	6	12	19	25,7	1,2	10	16,6
PMV	0,99	0,60	0,22	0,32	2,28	1,51	1,48	1,69	2,11	1,03	1,01	1,23
PPD	26,1	12,7	6,3	7,4	87,3	52,1	51,3	61,7	80,88	27,25	29,56	37,71

Table 4: Reference values for indoor air parameters (ASHRAE, ISO 7730)

Reference	Indoor air temp (°C)	Relative hum.(%)	Air velocity(m/s)	Average radiant temp. (°C)	Operative temp. (°C)	PMV	PPD
ASHRAE-55	22-24	30-60	0,16	NA	The highest indoor temperature change of 2.2 °C in a 1 hour period	NA	NA
ISO 7730	22-24	30-70	0,19	NA	22±2	NA	NA

3.2. Analysis of perceived and measured thermal comfort parameters

51 of the 202 measurements made by applying the survey were made in the summer period, 52 in the autumn period, 54 in the winter period and 45 in the spring period. The distribution of the answers given by the participants is given in the tables. It was seen that the PMV values calculated for the heating and cooling period did not meet the generally acceptable thermal comfort values defined in the standards (-0.5<PMV<+0.5). This reference range includes the 90% acceptability limits required for a high thermal comfort standard. The comfort data calculated for the cooling period, the measured PMV value is 2.11 and the PPD value is 80.88%. Based on the answers given by the workers in the surveys for the same conditions, the AMV value is calculated as 2.33 and the APD value is 89.30% (Table 5). These data indicate that the environment is not at an appropriate level in terms of thermal comfort. It can be said that the activity conditions of the workers requiring intensive limb movement due to working on machines, their clothing conditions (work clothes and equipment), indoor air temperature, air flow rate and relative humidity values create this inappropriate situation (Kon and Caner, 2023). Reference values used in the calculations are given in Table 4.

Table 5: Perceived and measured thermal comfort parameters during the summer period.

Parameter	Measurement			Occupant	Perceived		
	Average. PMV	Comfort	Ort.PPD		AMV	Comfort	APD
Whole	2,11	Hot	80,88	51	2,33	Hot	89,30
Male	2,13	Hot	81,70	39	2,39	Hot	90,70
Female	2,06	Hot	78,20	12	2,17	Hot	83,70
clo 1,0	1,65	Hot	60,11	8	0,88	Sligtly warm	21,20
clo 1,2	2,20	Hot	84,74	43	2,61	Too hot	95,40
≤30 Age	2,12	Hot	80,89	23	2,35	Hot	89,70
>30 Age	2,11	Hot	80,86	28	2,32	Hot	88,90
1,5 met	1,65	Hot	60,11	8	0,88	Sligtly warm	21,20
2,0 met	2,20	Hot	84,74	43	2,61	Too hot	95,40

When the heating period data were examined, the measured PMV value was calculated as 1.03 and the PPD value as 27.25%. When the worker survey results were examined, the AMV value was calculated as 0.57 and the APD value as 11.9% (Table 6) for the same conditions, and it was seen that the environment was not suitable in terms of participant preferences. It was seen that the measured and calculated results in the current comfort conditions overlap with the participants' preferences for the heating and cooling periods. No significant difference was observed between the calculated PMV value and the AMV value showing worker preferences.

Table 6: Perceived and measured thermal comfort parameters during the winter period.

Parameter	Measurement			Occupant	Perceived		
	Avrg. PMV	Comfort	Avrg.PPD		AMV	Comfort	APD
Whole	1,03	Sligtly warm	27,254	54	0,574	Sligtly warm	11,9
Male	1,03	Sligtly warm	27,25	43	0,488	Neutral	10
Female	1,02	Sligtly warm	27,27	11	0,909	Sligtly warm	22,4
clo 1,2	1,066	Sligtly warm	29,08	12	0,917	Sligtly warm	22,8
clo1,5	1,018	Sligtly warm	26,73	42	0,476	Neutral	9,7
≤30 Age	1,018	Sligtly warm	27	24	0,5	Sligtly warm	10,2
>30 Age	1,036	Sligtly warm	27,46	30	0,633	Sligtly warm	13,4
1,5 met	1,066	Sligtly warm	29,08	12	0,917	Sligtly warm	22,8
2,0 met	1,018	Sligtly warm	26,73	42	0,476	Neutral	9,7

For the autumn period, PMV value 1.01 and PPD value was calculated as 29.56% (Table 7), PMV value for the spring period PMV is 1.23 and PPD value is 37.71% (Table 8). While the environmental conditions related to PMV value are defined as 'Sligtly warm', the worker preferences stated that the environment is 'Sligtly warm'. The calculated PMV values and AMV values that express the thermal perception of the workers coincide in the same direction.

Table 7: Perceived and measured thermal comfort parameters during the autumn period.

Parameter	Measurement			Occupant	Perceived		
	Avrg. PMV	Comfort	Avrg.PPD		AMV	Comfort	APD
Whole	1,01	Sligtly warm	29,56	52	0,89	Sligtly warm	21,50
Male	0,98	Sligtly warm	28,47	41	0,88	Sligtly warm	21,30
Female	1,15	Sligtly warm	33,65	11	0,91	Sligtly warm	22,40
clo 1,2	0,37	Neutral	63,90	8	0,50	Sligtly warm	10,20
clo1,5	1,31	Sligtly warm	33,49	44	0,96	Sligtly warm	24,30
≤30 Age	0,99	Sligtly warm	29,45	24	1,00	Sligtly warm	26,10
>30 Age	1,03	Sligtly warm	29,66	28	0,79	Sligtly warm	18,00
1,5 met	0,37	Neutral	63,90	8	0,50	Sligtly warm	10,20
2,0 met	1,31	Sligtly warm	33,49	44	0,96	Sligtly warm	24,30

While the environmental conditions related to PMV value are defined as 'Sligtly warm', the worker preferences stated that the environment is 'Sligtly warm'. is clearly seen that as the clo value increases and the met value increases, the thermal comfort values also increase.

Table 8: Perceived and measured thermal comfort parameters during the spring period.

Parameter	Measurement			Occupant	Perceived		
	Avrg. PMV	Comfort	Avrg.PPD		AMV	Comfort	APD
Whole	1,23	Sligtly warm	37,71	45,00	0,76	Sligtly warm	17,00
Male	1,16	Sligtly warm	35,57	31,00	0,45	Neutral	9,30
Female	1,38	Sligtly warm	42,47	14,00	1,43	Sligtly warm	47,10
clo 1,2	0,87	Sligtly warm	21,19	12,00	0,42	Neutral	8,60
clo1,5	1,36	Sligtly warm	43,72	33,00	0,88	Sligtly warm	21,30
≤30 Age	1,15	Sligtly warm	36,48	19,00	1,00	Sligtly warm	26,10
>30 Age	1,28	Sligtly warm	38,61	26,00	0,58	Sligtly warm	12,00
1,5 met	0,87	Sligtly warm	21,19	12,00	0,42	Neutral	8,60
2,0 met	1,36	Sligtly warm	43,72	33,00	0,88	Sligtly warm	21,30

4. CONCLUSIONS

In this research, the thermal comfort conditions of the work area were examined according to the standards, and the efficient environmental conditions of those working in the machining sector in the industry were revealed. The necessary ethical approval document and permissions for the survey and measurements applied in the study were obtained from the company.

In line with the data obtained from the factory field study;

- The average and maximum PMV values are above the standard reference values for the cooling period. 13.73% of the AMV values for the cooling period, 88.89% for the heating period, 71.15% for the autumn period, and 64.44% for the spring period are in the comfort range. 3.92% of the PMV values for the cooling period, 98.15% for the heating period, 80.77% for the autumn period, and 80% for the spring period are in the comfort range. The environment conditioned at 20 ºC with industrial heating in all months of the heating period provides comfort conditions and increases employee satisfaction and performance. Since the heating system is also activated in some months of the transition periods, the thermal sensation of employees reaches a highly acceptable level.

- Indoor temperatures were measured as 28.57 ºC for the cooling period, 21.43 ºC for the heating period, 21.80 ºC for the autumn period and 23.26 ºC for the spring period. The measured temperatures fall within the 22-24 ºC comfort temperature range referred to in ASHRAE-55 and ISO 7730 standards, excluding the cooling period. This data was compared with the employee satisfaction evaluation and it was seen that the two data overlapped. During the cooling period, employees need conditioned and improved environmental conditions according to the reference values of the standards.

- When the activity level (those who design, model, test and measure in the office have a metabolic rate of 1.5, those who work standing at the machine in the machining process have a metabolic rate of 2.0) differences are evaluated during the heating, cooling and transition periods (autumn and spring), it is seen that there is a significant difference and therefore the activity difference has an effect on thermal comfort. People who work in heavy jobs in industrial facilities work at higher activity levels. Therefore, the comfortable ambient temperature may be lower for employees with a high activity level, i.e. metabolic rate.

- When the clothing status of those working at the machine in the machining process in the heating, cooling and transition periods (autumn and spring) is evaluated by taking into account the 1.5 clo criterion, the clothing status of those working in the machining process creates a significant difference. The work clothing status of the workers in the machining process where the field study was conducted was determined with the clothing insulation values given in ISO 7730 Annex C and the effect of these insulation values on the optimum temperature. Field study results have shown that workwear with 1.5 clo insulation can create a change between 0.9 ºC and 2.5 ºC in optimum working temperature.

CONFLICT OF INTEREST

The authors declare no conflicts of interest.

AUTHOR CONTRIBUTIONS

Şükran ÖZBAĞ: Determination and management of the conceptual design process, literature review and critical review. İsmail CANER: Literature review, experimental design, data collection, data analysis and interpretation. Nadir İLTEN: Experimental design and management, data analysis and interpretation, critical review.

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