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An Investigation of Thermal Comfort for Mold, Welding and Turning Technicians and the Effects on Performance in Naturally Ventilated Area

Kemal Furkan Sökmen*[1]

Abstract

In this study, thermal comfort measurements were made for mold, welding, and turning technicians in naturally ventilated industrial establishments. Metabolic rates were determined as 100 W/m2 for welding and turning and 190 W/m2 for mold technicians. The clothing insulation factor was calculated as 0.68 clo. The measurements were done in three different companies on 17-19 July 2017 during working hours without stop working. In terms of PMV findings, it was determined that the thermal comfort conditions are not met according to the ASHRAE standard. As for the WBGT value, it was determined that there was heat pressure on 17.07.2017 and there was no heat pressure on 18.07.2018 on all the employees. On 19.07.2017, it was determined that there was a heat pressure after 13:00 for mold technicians and after 17:00 for welding and turning technicians. Calculated PMV values were compared with the survey results and ıt was determined that results were compatible with values. It was made firm that people who were overweight and obese felt their working environment warmer than normal weight worker. The performance loss ratios which are dependent on ambient temperature were calculated and compared with the literature and was determined that they are compatible.

Keywords: Ergonomics of thermal environment, employee performance, heat stress, thermal comfort measurement

1. INTRODUCTION

In recent years there has been an increase in work on parameters affecting employee performance, work continuity. The main parameters affecting thermal comfort were determined as air temperature, humidity, air velocity, and radiation [1]–[4]. The main parameters required for the comfort of the work environment have been determined in ASHRAE (55-2004) and ISO (7730) [5], [6]. In addition, PMV (Predicted Mean Vote) thermal comfort parameter was found by calculation based on employee metabolic rate, clothing characteristics, ambient air temperature, speed and humidity [7], [8]. In the determination of the thermal comfort conditions, it is necessary to determine the heat stress on the employee. WBGT (Wet-Bulb Globe Temperature) is a value which expresses the heat pressure on employee. The WBGT index is based on international

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standards and is an index originally set in 1950 during studies conducted within the US army. [9], [10]. In the studies conducted, it has been determined that the performance and the health of the employees are influenced by the thermal comfort of the environment by 54%. It has been found that employees experience extreme fatigue and focus problems due to temperature. Accordingly, it has been observed that the thermal comfort of the working environment directly affects the production capacity and the employee's job continuity [11]–[13]. Another study showing that thermal comfort affects the production has been made by [14] . In the survey conducted in the research, the employees stated that they had to stop working because of the heat, they could not finish the work on their hands, and they needed more time to finish the work. For this reason, thermal comfort is positioned among the basic parameters of productivity, efficiency, and employee comfort [15]. In one of the studies on thermal comfort, the effects of comfort conditions on employee performance has been examined in detail and a 10% increase in performance has been recorded after improving the comfort conditions [16] . It has been stated that heat stroke, heat cramps and some pathological effects were observed as thermal inconvenience continues. In another study, it was determined that there was noticeable decrease in the employee performance when the WBGT value is operating at 32.22°Cand above. It has been found that the WBGT value has a negative effect on learning and memory skills when working at or exceeding 26.67°C [17]. The studies that examine the relationship between air temperature and employee performance have revealed that the performance decreases with the increasing temperature [18], [19]. In this study, besides the automated production lines which have been developed by the advanced technology, the comfort conditions and the performances related to the thermal comfort of the occupational groups who are working with the welders, lathe and manual molding and which are among the most important professions still active in our country's industry are examined. In the study, garment insulation factor and metabolic rate calculations were done via DeltaLog software. Comfort measurements were made with Delta OHM 52.1 measuring devices.

2. MATERIALS

The PMV value is a 7-point thermal sensitivity chart of ASHRAE which indicates the thermal comfort perception level of the employee, and records the temperature or coldness felt in the environment (Table.1). The chart varies between -3 and +3. The PMV value is calculated Manuel C.Gameiro, (2014:2) with the given equation. PPD value is Manuel C.Gameiro, (2014:3)again calculated with the Equation 1.

$$PPD = 100 - 95.e^{-(0{,}03353.PMV^4 + 0{,}2179.PMV^2)} \quad (1)$$

The WBGT index is the result of two derived parameter measures, the natural wet-bulb temperature (t_{nw}) and the radiation temperature (t_g) and in some cases the air temperature (t_a) (dry chamber temperature. In calculation of WBGT, the given Equation 2 is considered TS EN 27243, (2002:2) for the external structures with solar charge [22].

Table 1. ASHRAE thermal sensation scale (Fanger, 1973:322)

Value	Perception
3	Hot
2	Warm
1	Slightly warm
0	Neutral
-1	Slightly cool
-2	Cool
-3	Cold

$$WBGT = 0{,}7t_{nw} + 0{,}2t_g + 0{,}1t_a \quad (2)$$

The obtained WBGT values are compared with the WBGT reference values given in Parsons (2006) and permitted in the ISO 7243 standard [23], [24]. The classification of metabolic rates and values that indicate the total amount of energy consumed in the body according to many working positions in the industry are given in TS EN 27243 (2002). In this study, metabolic rate values were taken from TS EN 27243 (2002) [22].

3. EXPERIMENTAL STUDY

The study was carried out within 3 days in three different companies that have welding, turner and molding room in the province of Bursa. For each company, tests were done on working hours. Tests were focused on welders, turners and manual molding/model makers. Measurements were made with Delta OHM 32.1 instrument (Fig.1). Calibration of measurement sensors is made in the Protos TURKAK control calibration laboratories, the official institution of the Republic of Turkey. Measurement range and error rate of measurement sensors are givenin Table 2. Measurements were done by team of Bilgemed Occupational Health and Safety Measurement Laboratory. Measurement equipments were placed at the nearest place to the employees in the departments in a way not to prevent the working conditions. Measurements were made during working hours between 07.17-07.19.2017.

Figure 1: Delta OHM 52.1

Table 2: Measurement ranges and error ratios of measuring instruments

Measuring instrument	Measurement range	Error ratio
Dry bulb temperature probe (TP 3207))	–10 °C to 100 °C	± 0.15%
Anemometer (speedometer)sensor (AP 3203)	0.05÷5 m/s	± 0.02 m/s (0.05÷1 m/s)
		± 0.1 m/s (1÷5 m/s)
Globe temperature probe Ø=150 mm ISO 7243- ISO 7726 (TP 3275)	–30 °C to 120 °C	± 0.15%
Wet bulb temperature probe (HP 3201)	+4 °C to +80 °C	
Humidity probe (HP 3217)	-30°C … +100°C Humidity 5%RH÷98%RH	± 2.5%

Employees' work clothes were examined and selected from DeltaLog software ass seen from Fig.2. Clothing insulation factor was calculated for all employee 0,68 clo

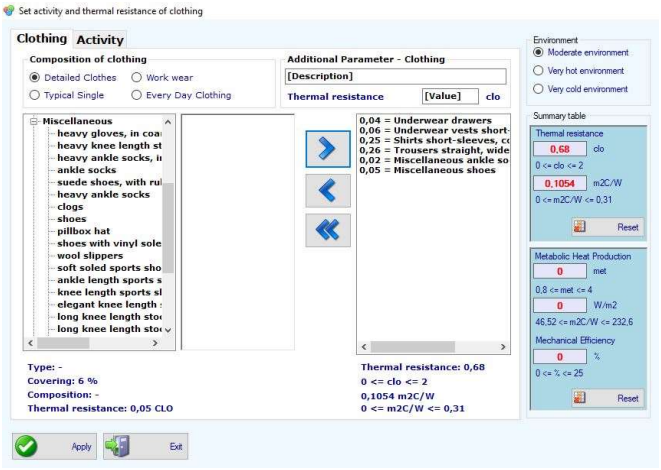
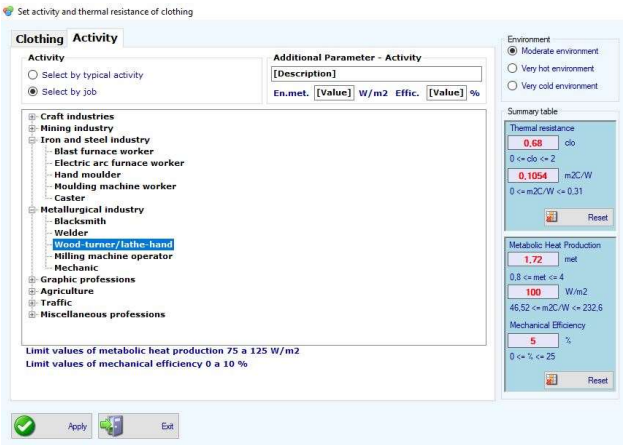
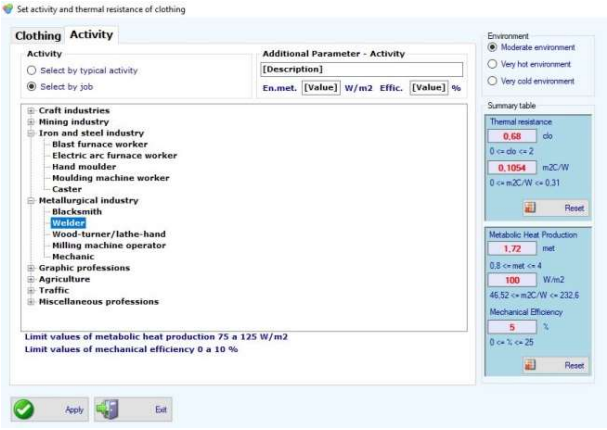


Figure.2: Selection of clothing and calculation of clothing insulation factor

Metabolic rates were selected for turning, welding and moulding technicians from DeltaLog software as indicated in Fig.3, in accordance with ISO 8996.



a)



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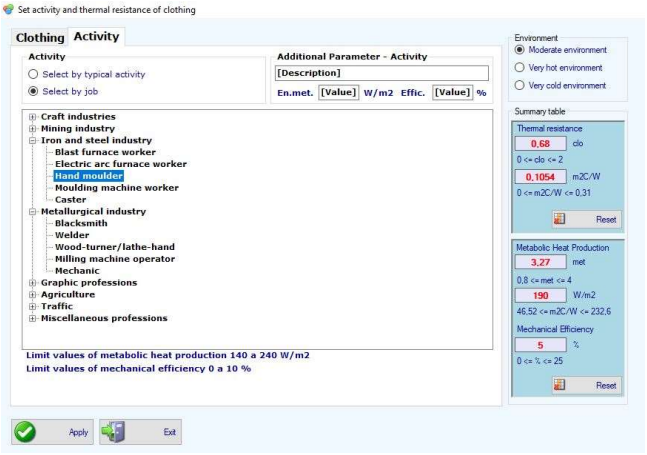

c)

Figure 3. a) Turner b) Welder c) Molder metabolic rate from DeltaLog software

Number of welding, moulding and turner technicians in three different companies given in Table 3**.**

It was found that measuremet areas were naturally ventilated in this study. As a result of the measurements, we determined that the air velocities were in the range of 0.1-0.14 m/s.

Table 3: Number of molder, turner and welder according to company

	Molder	Welder	Turner
1.Firm	4	5	2
2.Firm	5	2	2
3.Firm	6	3	4

Since the measurements at every firm were made on different days, temperature and humidity ratios were different. Average temperature and relative humidity ratios of the measured days aregiven in Table 4.

Table 4: Average daily temperature and humidity

	17.7.2017	18.7.2017	19.7.2017
Ave.Temp. (°C)	28,3	24,5	25,3
RH (%)	50	90	90

In order to compare the data obtained by calculation in the study, a survey study was conducted for the occupational groups. No record of names was taken in order to protect the personality rights of employees in the survey study. Participation in the survey was voluntary. Firms and employees were informed in advance about how the results of the study will be used. According to this information, the study o questionnaire was carried out with the resolution of Bursa Technical University Ethics Committee number 69707128-050.99. Weight and height were taken into anonymous forms for the determination of the body mass index of the subjects in the questionnaire (Table.5). Occupational groups are asked to evaluate the environment they belong to according to the heat sensitivity chart in Table 1.

Table 5: Body mass index

Body Mass Index (BMI)	
BMI>18,5	Low Weight
18,5<BMI<24,9	Normal Weight
25<BMI<29,9	Over Weight
30<BMI<40	Obese
BMI>40	Over Obese

4. RESULTS

The metabolic rate of each occupational group, calculated PMV, PPD and WBGT values are given in Table 5 as minimum and maximum. Since the PMV value change graphs calculated according to the results obtained from the measurements made during working hours are similar to the daily mean temperatures of 07.18-07.19.2017they are given in detail in Figure 4. PMV values calculated on 07.17.2017 are calculated in the morning hours, the start time of the work for welding and lathe technician as 1,62 at 08:00 and its maximum value as 3,17 at 15:00; at the start time of the working hours for the mold maker was 2.94 at 08:00 and the maximum value was 4.2 at 15:00. 07.17.2017

is the day that the average daily temperature is the highest among the measurement days. It is the day which the relative humidity is the lowest at 50%. The PMV values calculated on 07.18.2017 were calculated in the morning hours for the welding and turning technician, at the start time as 1.27 at 08:00 and the maximum value as 1,93 at 17:00; at the start time of the working hours for the mold technician as 2.68 at 08:00 and the maximum value as 3.15 at 17.00. 07.18.2017 was the day which the the average daily temperature is 24,5 ° C and the relative humidity is highest at 90%. The PMV values calculated on 07.19.2017 were calculated in the morning hours for the welding and turning technician, at the working hours start time as 0.85 at 08:00 and the maximum value as 2.39 at 17:00; at the working start time for the moulding technician as 2.33 at 08:00 and the maximum value as 3.55 at 17:00. 07.19.2017 was the day which the average day time temperature within the day was 25.3 ° C among the measured days and the nearest day to the environment air temperature on 07.18.2017. The relative humidity was again the same day on the 07.18.2017, measured at 90%.

The change graph of WBGT values are given based on the low and medium metabolite steep ratio limit values (Table 2) comperatively in Fig.5 The WBGT value was calculated based on Equation 2.

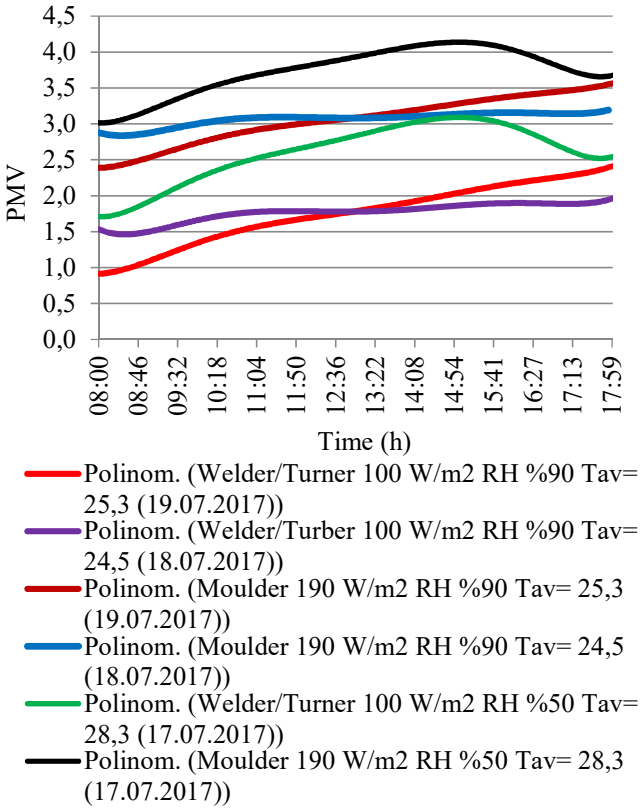

Figure 4 Calculated PMV values on 17-18-19.07.2017

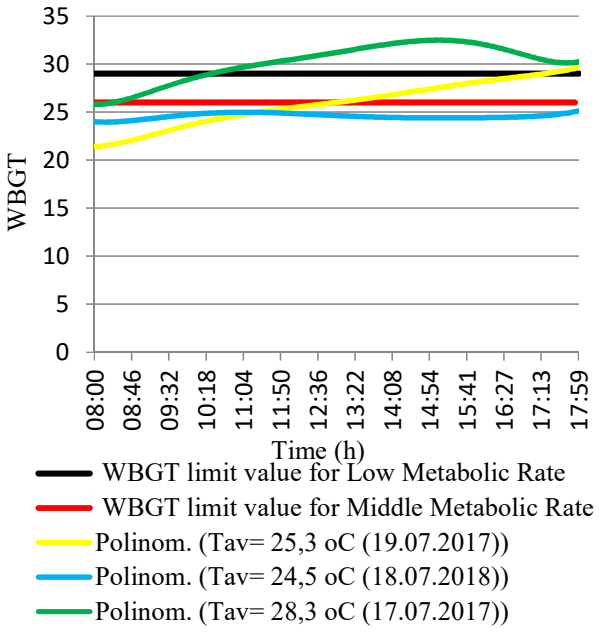

Figure 5. Change of PMV values with increasing temperature between 08:00-18:00

The WBGT value is the result of the natural wet bulb temperature (t_{nw}) with the radiation temperature (t_g) and the air temperature (t_a) (dry chamber temperature). For this reason, the metabolic rates of employees do not have an effect on the WBGT value. The minimum WBGT value for 07.18.2017 was calculated as 23,69°C and the maximum value as 25.10°C. The lower metabolic rate thermal stress threshold limit value of both of these two values are lower than 29°C and the medium metabolic rate thermal stress threshold value is lower than 26°C As can be seen from Figure 5, threshold value for the lower and medium metabolic rate was not exceeded and no thermal stress was observed on the employees on 07.18.2017, which is the day when the daily average temperature value was the lowest.

Whereas the WBGT values calculated for the day 07.19.2017, where the daily average temperature was 25.3°C, were minimum 21.10°C and maximum 29.55°C . It was observed that the thermal press threshold limit value of the mold maker working in the medium metabolic area was exceeded after 13:00 and that after this hour thermal press has occurred on the mold maker. It is indicated that the temperature of 29°C which is the thermal press value for the welding and lathing technician, was exceeded at around 17:00 and thermal press occured on the welding and lathe technicians during the last hour of workingin Fig. 5.

As the minimum WBGT value was 25,38°C for the day 07.17.2017, on which the average daily temperature was the highest, and maximum was calculated as 32.82°C. It was found that the thermal press value for the mold maker (26°C) was exceeded immediately at the beginning of the working hour and the employee worked under the thermal pressure throughout the day. It was determined that the critical WBGT value for welding and turning technicians was exceeded around 10:15 and the employees were under thermal stress until the end of working hour

It was determined that increasing temperature and PMV value are consistent with PMV rising slope given in the study of rise (Atmaca, ve diğ. 2007 :3214) for low and medium metabolic rate (Fig. 6). The results of the survey for morning hours and afternoon are given in Table 6.

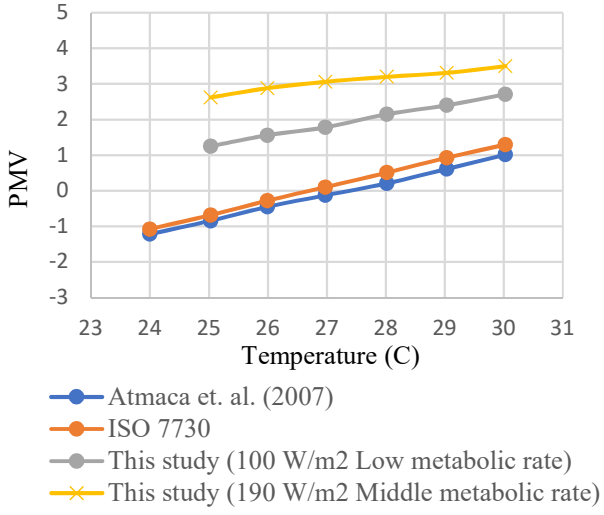

Figure 6. Change of PMV according to increasing temperature

According tothe results of the questionnaire made on 07.17.2017 (1. Firm) the mold maker described the before and afternoon as hot (3) as the calculated values. It was found that while three of the welder and lathe technicians evaluated the

working environment as warm (2), two of them evaluated as hot (3). It was determined that the employees who made their evaluations as warm before the noon were overweight according to Table 5 in terms of VKE. For after noon, all the technicians evaluated the environment as hot (3).

Table 6: Survey results

	Mold Technician	Welding Technician	Turning Technician
	PMV	PMV	PMV
1. Firm 17.07.2017	S:3,Ö:3	S:2,Ö:3	S:2,Ö:3
	S:3,Ö:3	S:3,Ö:3	S:2,Ö:3
	S:3,Ö:3	S:2,Ö:3	
	S:3,Ö:3	S:2,Ö:3	
		S:3,Ö:3	
2.Firm 18.07.2017	S:3,Ö:3	S:1,Ö:2	S:2,Ö:3
	S:3,Ö:3	S:1,Ö:2	S:1,Ö:2
	S:3,Ö:3		
	S:3,Ö:3		
	S:3,Ö:3		
3.Firm 19.07.2017	S:3,Ö:3	S:1,Ö:2	S:1,Ö:2
	S:3,Ö:3	S:2,Ö:3	S:2,Ö:3
	S:2,Ö:3	S:2,Ö:3	S:1,Ö:2
	S:2,Ö:3		S:2,Ö:3
	S:2,Ö:3		

Also in the surveys made on 07.18.2017 in the 2.Firm, the mold technicians described the environment as hot (3) in the morning and after noon. Among the welding and turning technicians, 3 people regarded their morning hours to be mild (1) and one person as warmer (2). It was determined that the employees who evaluated the environment as warm for morning hours were overweight according to VKE. While 3 employees defined the environment for noon hours as warm (2), VKE pver weight employee defined the working environment as hot (3).

On 07.19.2017,in the survey study carried out in the 3. Firm, whereas 3 of the molding technicians defined the environment as mild (2), the other 2 defined as warm (3). It was found that the people who defined the environment as hot were obese and overweight according to VKE. Mold technicians made their evaluations for afternoon as hot (3). It was seen that 3 of the welding and turning technicians evaluated the environment as mildly warm (1) and 4 of them evaluated as warm (2) for the morning hours. Whereas the same 3 people who evaluated the mornings as mildly warm (2) and the same 4-person defined the environment as hot (3). It was found that the welding and turning technicians who regard the morning hours as warm (2) and the afternoon as hot (3) are overweight and obese according to VKE.

It was determined that the thermal comfort parameter PMV value calculated on the dates of the measurements made according to the working metabolic rate was also outside the limits of -0.5<PMV<0,5 given inAnsi/Ashrae, 2004 . For the three days which are measured, decrease in the working performance due to the temperature (Seppanen et al. 2003: 3) was calculated according to the Equation 3 and is given in Figure 7 as comparatively.

$$P\ (\%) = 2\ x\ (Temp.) - 50 \qquad (3)$$

The greatest decrease in the performance of employees was determined on 07.17.2017, which is the day when the working environment temperature was measured highest with a rate of 6.6%. Figure 7 shows that there is no performance loss at the average operating temperature of 24.5° C on 07.18.2017 and a 1% performance loss on 07.19.2017 when the working environment temperature is 25.3 °C.

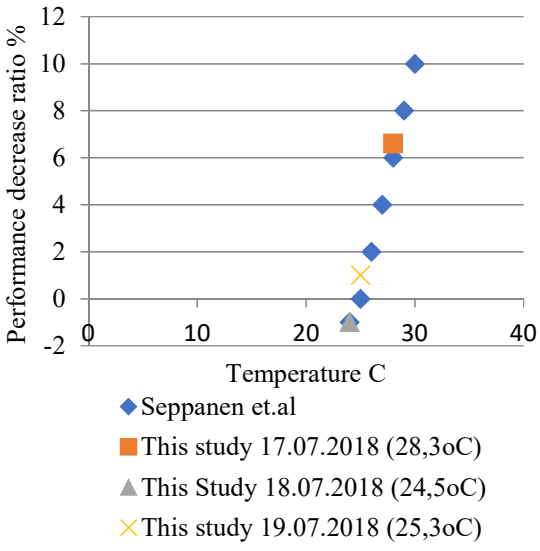

Figure.7: Sıcaklığa bağlı performans düşüşü

5. DISCUSSION

In our study which focuses on the thermal comfort of the employees working in the moulding sector, the universal lathe use and welding process, which are very common in our country, although the use of technology has improved with the developing technology in the production methods, measurements were made for welding and lathe technicians in 3 companies within three days with te-the devices ofwhich the Delta OHM 52.1 specifications are given in Table 2. PMV and WBGT values were calculated based on the measurement values with the help of Equations 2 and [20]. According to the calculated PMV values, it was determined according to the [5] standard, none of the three companies does conform to thermal comfort conditions. Measurements were made during working hours throughout the day. The changes in PMV and WBGT values were monitored according to the variation of ambient temperature and are given in Figures 4 and 5. It was indicated that the measurement and calculation values which were measured in the morning hours were generally low and PMV and WBGT critical values were in the afternoon. Starting from the morning hours, the rising temperature and work load caused us to observe a more critical time period in terms of thermal comfort parameters. For this reason, we considered that the measurements should be done in the afternoon or during the day in order to make accurate determinations in field measurements in the occupational security sector. Figure 4 indicate that the PMV value, which is a thermal comfort parameter, directly affects employee metabolic rate. According to lathe and welding technicians, the mold maker has been the occupational group who felt most comfortless in terms of PMV value in three different days regardless of the company difference. Mold technicians were the group with the highest metabolic rate because they are doing manual corrections and fine work on the mold. In the research, while the welding technicians was expected to feel more uncomfortable, it was found that the welding job is more in the form of spot weld and the worker can work from a fixed position without moving. The result of the study revealed that it may be right that the occupational groups who are engaged in heavy workmanship can be advised to periodically change their work. It was observed through Equation 3 that the performance of employees decreased In the situations which the ambient temperature exceeds 25°C Seppanen et al. (2006). In this study, performance values from the average working temperature for three days were calculated according to Equation 10 and compared with the literature and found to be in accordance with the literature. It was determined that the day on 07.17.2017, which the average working environment temperature was the highest, was also the day which the performance loss was at the highest level with 6,6%. Whereas in terms of performance, the ideal temperature was 25ºC, this temperature was determiend to be insufficient for thermal comfort. Only the reduction of temperature affects the performance according to Equation 10. It was found that the parameters such as ambient humidity, air velocity, air temperature and especially the worker's metabolic rate have to be changed to be able to provide thermal comfort. If the ventilation cannot be provided with the conditioned air, it may be effective to have workers work alternately with lower metabolic rates.

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