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Investigation of the Change in the Work Environment and in Thermal Comfort Satisfaction of the Natural Stone Industry Employees

Ali Ekrem Arıtan,[1] Cem Şensöğüt[2*]

[1] Afyon Kocatepe University, Mining Engineering Department, Afyonkarahisar,Turkey
[2*] Kütahya Dumlupinar University, Mining Engineering Department., Kütahya,Turkey

* Email: cem.sensogut@dpu.edu.tr

Abstract: Natural stones have been widely used for buildings, works of art/structures, flooring, etc. since ancient times. The fact that the stone can be used without the need for excessive processing, being directly extracted from the quarry, shaped and used is perhaps one of the main reasons why we come across natural stones in many structures around the world. Natural stones, which have been used in many buildings for thousands of years, need to be produced much more with the increase in the human population. With the increase in production, the number of quarries and employees, and the mechanization have brought many problems, such as accidents and occupational diseases. A person's performance is proportional to his comfort. The comfort of the employee is directly related to the good health and safety conditions in the working environment. One of the most important factors determining human comfort in the working environment is thermal comfort. One of the seasonal challenges faced by those working in natural stone quarries is extremely hot or cold weather. In this study, the thermal comfort conditions of the workers in the natural stone quarry and natural stone processing plant were investigated.

Keywords: Thermal comfort, mining, occupational health and safety.

Introduction

Mining is one of the oldest known business lines. The natural stone sector is also among the locomotives of Türkiye's mining. Türkiye located in the Alpine belt is in the region of the world's richest marble deposits. The country's probable marble reserves are approximately 13.9 billion tons (5.1 billion m^3). This amount corresponds to 33% of the world's total reserves, which are estimated to be 15 billion m^3 (TCTB, 2021).

In Turkey, there are natural stone reserves in colors and patterns that can meet the appreciations. These are crystalline limestone (marble), limestone, travertine-formed limestone (onyx), conglomerate, breccia and rocks of magmatic origin (granite, syenite, diabase, diorite, serpentine, etc.). Türkiye's natural stone reserves are spread over a wide region throughout Anatolia and Thrace. Distribution of the total natural stone reserves are 32% in the Aegean, 26% in Marmara, 11% Central Anatolia, and 31% in the Eastern Anatolia, Southeastern Anatolia, Black Sea and Mediterranean regions, respectively (RTMC, 2021).

In parallel with the increasing population in the world, production is increasing day by day in order to meet the demand for natural stone in the construction industry. With this increase, problems in terms of occupational health and safety also increase in production areas. These problems appear as work accidents and occupational diseases.

Physical risks such as vibration, noise, thermal comfort create problems for those working in mining. In the natural stone sector, which is a branch of mining, is a business area with a high exposure to physical risks, thermal comfort problems arise due to the prevalence of open pit mining. In hot and cold weather, problems arise for employees due to the fact that the work is carried out in the open field.

One of the biggest factors in an employee's performance work is to have a comfortable environment. Ambient comfort (ergonomic, thermal) will certainly have an impact on the employee's performance. Conducting studies on the risks of diseases caused by high or low temperatures in working environments is beneficial for improving the health and work efficiency of employees (Xiang et al., 2014: Arıtan and Memiş, 2022).

While the workers working in the quarries where natural stone production is made are directly exposed to sunlight. The thermal comfort values vary as the machine operators working in the closed cabin are exposed to different degrees of air temperature with the heating of the cabin. In the working environment where thermal comfort is high, work efficiency also increases (Olesen, 1985).

It is appropriate to measure thermal comfort in hot environments with the TS EN ISO 7243 standard, in warm environments with the TS EN ISO 7730 standard, and in cold environments with the ISO 11079 standard (TS EN ISO 7730; TS EN ISO 7243; ISO 11079).

During the present work, thermal comfort measurements were taken in the working environments of the employees/operators dealing with different jobs in the field and within the processing plant (physical worker, loader operator, etc.).

Thermal Comfort Indices Used

When the literature is examined, it is seen that many indices are used in the evaluation of thermal comfort measurements such as Predicted Mean Vote (PMV), Predicted Percentage of Dissatisfaction (PPD), Wet Bulb Globe Temperature (WBGT), Universal Thermal Climate Index (UTCI) et al. (Arıtan and Memiş, 2019).

We can say that Thermal Comfort Measurements are made in three stages depending on the degree of the ambient temperature;

PMV-PPD index is calculated with the TS EN ISO 7730 method. If the PMV value of the environment is between -2 and +2 according to the standard, the evaluated environment is suitable in terms of thermal conditions. An additional evaluation is required If the PMV value is greater than +2, according to the standart TS EN ISO 7243 (Ergonomics of the thermal environment - Evaluation of heat stress using the WBGT standard), if the PMV value is less than -2, according to the standard TS EN ISO 11079 (Ergonomics of the thermal environment – Determination and interpretation of cold stress using clad insulation and local cooling effects) (TS EN ISO 7730; TS EN ISO 7243: 2017; TS EN ISO 11079).

Material and Methods

Thermal comfort measurements were taken from the natural stone enterprise (processing plant and open pit) located within the provincial borders of Afyonkarahisar in the Agean region of Türkiye. Measurements were taken for field workers, operators and processing plant workers in accordance with the standards. Indoor measurements were evaluated according to the PMV-PPD index, and outdoor measurements were evaluated according to the WBGT index.

Measurements were realized by the use of DELTA OHM WBGT 32.3 device (Fig.1), with special probes in accordance with TS EN ISO 7730 (PMV-PPD) and TS EN ISO 7243 (WBGT) standards.

Fig. 1 Delta OHM WBGT 32.3 thermal comfort measuring device.

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PMV-PPD

According to TS EN ISO 7730 standard, the PMV-PPD index can only be used when the PMV values between -2 and +2 and the six main parameters satisfy the ranges given in Table 1.

Table 1. PMV-PPD index usage ranges.

Parameters	Ranges
Metabolic Rate (M)	46 W/m^2 ile 232 W/m^2 (0,8 met - 4 met)
Radiant Temp. (t_r)	10ºC to 40ºC
Dry Temp. (t_a)	10ºC to 30ºC
Air pressure (p_a)	0 Pa to 2 700 Pa
Airflow velocity (v_{ar})	0 m/s to 1 m/s
Clothing coefficient (I_{cl})	0 m^2. K/W to 0,310 m^2. K/W (0 clo - 2 clo)

PMV index is a very comprehensive index with its details and calculations. The index is formed as a result of the calculation of many variables in the equation below. We can collect the variables used in the equation under two main headings.

In the first title, the meteorological variables are humidity, wind speed, mean radial temperature and dry air temperature. In the second title, there is the clothing coefficient depending on the clothes worn by the employees and the metabolic rate depending on the work they do (Yıldırım and Altınsoy, 2015).

F_{cl} =1+1.29*I_{cl} If I_{cl}<= 0.078 m^2.K/W

1.05+0.645*I_{cl} If I_{cl}>0.078 m^2.K/W

h_c=2.38*(t_{cl}-t_a)0.25 If 2.38*(t_{cl}-t_a)0.25>12.1*√V_{ar}

12.1*√V_{ar} If 2.38*(t_{cl}-t_a)0.25<12.1*√V_{ar}

t_{cl}=35.7–0.028*(M-W)-I_{cl}*{3.96*10-8*f_{cl}*[(t_{cl}+273)4-(t_r+273)4]+f_{cl}*h_c*(t_{cl} -t_a)} (1)

PMV=[0.303*e(-0.036*M)+0.028]*{(M-W)-3.05*10-3*[5.733-6.99*(M-W)p_a]0.42*[(M-W)-58.15]-1.7*10-5*M*(5867-p_a)-0.0014*M*(34-t_a)-3.96*10-8*f_{cl}* [(t_{cl}+273)*4-(t_r+273)*4]+f_{cl}*h_c*(t_{cl}-t_a)} (2)

M: Metabolic Rate (W/m^2), W: Effective Mechanical Power (W/m^2), I_{cl}: Clothing Insulation (m^2*K/W) f_{cl}: Clothing insulation area factor, t_a: Dry chamber (air) temperature (°C)), t_r: Average radial temperature (°C), V_{ar}: air flow velocity (m/s), p_a: partial vapor pressure (Pa), h_c: Convective heat transfer coefficient (W/(m^2*K)), t_{cl}: Clothing surface temperature (°C). (Table 2).

Table 2. Description of PMV values.

PMV	Description
+3	Hot
+2	Warm
+1	Mild warm
0	Neutral
-1	Slightly cool
-2	Cool
-3	Cold

The PPD value is an index derived from PMV that gives the numerical percentage of dissatisfied people in terms of thermal comfort in the working environment. PPD value is derived according to the Equation 3.

$$PPD = 100 - 95 \times e^{-(0.03353 \times PMV^4 + 0.2179 \times PMV^2)} \quad (3)$$

(Epstein and Moran 2006; Fanger, 1972; Hwang et al. 2009; Parsons 2005; Yıldırım and Altınsoy, 2015) .

PMV ±0.5, the rate of dissatisfied people in the environment does not exceed 10%. This shows us the most ideal working environment in terms of thermal comfort.

While measuring with this method, the metabolic rate of the work realized, the clothes worn by the personnel, the ambient temperature, humidity and air flow rate parameters are measured. A PMV index is calculated using the measurement results. This index has a value in the range of -3 to +3, and if it is outside the range of -2 to +2, it indicates that there may be a thermal condition in the environment that may impair the health of the person. In this case, a second measurement is required for hot environments. If the measurement result is in the desired range, the PPD value gives us the information that how many of the people working in this environment are not satisfied with the ambient conditions. In order to reduce this rate, the firm can work to get closer to the ideal environmental conditions (TS EN ISO 7730).

-WBGT

The WBGT index is one of the experimental indexes and shows the heat pressure that the person is exposed to (Alfano et al., 2014; Arıtan and Memiş, 2022).

Examining the risks of diseases caused by high temperature during work is beneficial for improving workers' health and work efficiency (Xiang et al., 2014). Employees exposed to high temperature; they are exposed to diseases such as heat stroke, heat exhaustion, heat cramps, hives, severe fatigue (Arıtan and Memiş, 2022; OSHA, 1999; NIOSH, 2009).

Table 3. TS EN 7243 Evaluation Table.

Metabolic rate class	Metabolic rate	Reference $WBGT_{eff}$ for heat acclimated persons	Reference $WBGT_{eff}$ for non-heat acclimated persons
0	115	33	32
1	180	30	29
2	300	28	26
3	415	26	23
4	520	25	20

WBGT Index Calculation is carried out as follows;

- ✓ Wet Bulb Temperature (T_{nw}),
- ✓ Radial (sphere) Temperature (T_g)
- ✓ Dry Bulb Temperature (T_a) is used.

WBGT Index;

- Environments with solar load:

$$WBGT = 0.7T_{nw} + 0.2T_g + 0.1T_a \quad (4)$$

- Environments without solar load:

$$WBGT = 0.7T_{nw} + 0.3T_g \quad (5)$$

Results and Discussion

Results from the field and processing plant are given in the charts below. While PMV-PPD indices were suitable for indoor measurements, WBGT index was found to be suitable for outdoor measurements.

Table 4. Thermal comfort results of Operators/Employees (WBGT Index)

Measurement	Loader operator	Excavater operator	Truck operator	Drilling operator	Employee 1	Employee 2	Employee 3
T_{nw} (°C)	33,8	34,2	30,9	32,7	33,6	33,1	33,9
T_g (°C)	40,2	39,8	34,2	34,9	41,5	39,3	40,7
T_a (°C)	35,1	37,6	30,6	33,8	36,9	35,6	36,2
WBGT (in) (°C)	35,2	35,7	31,5	33,3	35,5	34,6	35,5
WBGT (out) (°C)	35,7	35,9	31,9	33,4	36,0	35,0	35,9

The results obtained were higher than the TS EN ISO 7243 standard. According to the standard, 29-30ºC was deemed appropriate. The results in the field vary between 35.0-36.0ºC. According to these results, Thermal comfort conditions are not suitable for operators and employees working in open pits.

Table 5. Thermal comfort results of natural stone processing plant operators and employees (PMV-PPD).

Data/Results	Block cutter/cutting machine employee	Gang saw machine worker	Polishing line worker	Forklift operator
Temperature (°C)	28,6	28,3	29,1	29,8
Humidity (%)	68	71	76	67
Air velocity (m/s)	0,28	0,19	0,12	0,21
Metabolic rate	2	2	2	1,5
Clo	0,61	0,61	0,61	0,61
PMV	0,92	1,09	1,35	1,24
PPD(%)	23	30	43	37
Sensation	Slightly Warm	Slightly Warm	Slightly Warm	Slightly Warm

According to the measurements taken at the plant, the forklift operator has a higher thermal comfort value than the ±0.5 PMV specified in the TS EN ISO 7730 standard for those working on the machines. This shows that there is a 23-43% dissatisfaction among the exposed employees. It can be worked on, but work should be done to eliminate the discomfort.

It was observed that there was an inconsistency in the thermal comfort feelings of the employees/operators in both regions. The following improvements need to be made.

- Attention should be paid to temperature, humidity, air velocity of the environment.

- Personal exposure times in the environment should be reduced.

- People's work clothes should be reviewed. Employees with different metabolic activities should be given different clothes.

- Considering all thermal comfort factors, studies should be carried out to ensure employee satisfaction.

- It should be ensured that the air-conditioning devices operate without fail in the working.

If the above-mentioned precautions are taken, the work satisfaction of the employees and operators will increase. With an increase in satisfaction, efficiency and thus profitability can be increased (Olesen, 1985).

One of the most critical points here is that the operator or employees exposed to direct sunlight (open pit operation) experience much more thermal discomfort than indoor (processing plant) employees. While indoor employees only work in a slightly warm environment, those who work outdoors, that is, in open field, work in a hot or even very warm environment.

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