IMPACTS OF HEAT EXPOSURE ON WORKERS' HEALTH AND PERFORMANCE AT STEEL PLANT IN TURKEY

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I certify that in my opinion the thesis submitted by Abdel Karim Fahed titled "IMPACTS OF HEAT EXPOSURE ON WORKERS' HEALTH AND PERFORMANCE AT STEEL PLANT IN TURKEY" is fully adequate in scope and in quality as a thesis for the degree of Doctor of Philosophy.

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This thesis is accepted by the examining committee with a unanimous vote in the Department of Energy Systems Engineering as a Doctor of Philosophy thesis. January 18, 2019

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The degree of Master of Science by the thesis submitted is approved by the Administrative Board of the Graduate School of Natural and Applied Sciences, Karabük University.

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“I announce that all the data inside this proposal has been accumulated and displayed in understanding with scholastic controls and moral standards and I have agreeing to the necessities of these controls and standards cited all those which don't start in this work as well.”

Abdelkarim Fahed

ABSTRACT

Ph.D. Thesis

IMPACTS OF HEAT EXPOSURE ON WORKERS' HEALTH AND PERFORMANCE AT STEEL PLANT IN TURKEY

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The importance of workers keeping up relative body comfort in steel plant is of great significance. This is because productivity, health, and safety rely upon it.

Laborers of Iron and steel plants are displayed to over the top radiant heat that causes bother and breaking focuses their execution. This study inquires about the affect of heat load on workers' wellbeing and action in Kardemir Steel Plant in Karabük-Turkey utilizing many heat stress indices. Joined field estimations what's more, surveys were completed over a period from June to Eminent 2016. An aggregate number of 100 workers reliably working within the steel plant from five one of a kind work environments were chosen. The wet bulb globe temperature (WBGT), the physiological strain (PSI), and the warm stretch (HSI) files were ascertained.

Workers' productivity level was evaluated by analyzing the connections between work capacities and particular WBGT levels against work intensities' curves and by utilizing the anticipated mean vote (PMV) - productivity model. The foremost raised estimations of WBGT were recorded in August, strikingly interior the blast furnace zone and continuous casting unit with cruel estimations of 31.32±0.8 °C and 31.34±0.74 °C independently, whereas the most noteworthy HSI was found out at the rolling mills unit with a esteem of 137.83% ±18.45. Approximately 86% of members whimpered of warm burden in the midst of summer since of warm waves, soil and gas emanations. Solid connections were found among PSI and WBGT indices with center body temperature (r=0.725 and r=0.721 separately) as well as the rate of pulse (r=0.648 and r=0.517). These are considered as the foremost suitable indices for surveying heat load influence on laborers' prosperity and execution.

Keywords **:** Heat load, Steel plant, Productivity, WBGT, HSI, PSI
Science Cod : 928.1.065

ÖZET

Yüksek Lisans Tezi

TÜRKİYE'DE DEMİR-ÇELİK FABRİKALARINDAKİ ISIYA MARUZ KALAN İŞÇİLERİN İŞ SAĞLIĞI VE PERFORMANSA ETKİLERİ

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Çelik fabrikasında çalışanların nispeten vücut rahatlığını koruyanların önemi büyük önem taşımaktadır. Bunun nedeni, verimlilik, sağlık ve güvencenin ona güvenmesidir. Demir ve çelik fabrikalarının işçileri, verimsizliğe ve kırılma performansına neden olan aşırı radyan ısıya sunulur. Bu çalışma, ısı yükünün Kardemir Çelik Fabrikası'ndaki Karabük-Türkiye'de birkaç sıcağı stres endeksi kullanarak işçilerin sağlığı ve aktivitesi üzerindeki etkisini araştırmaktadır. Saha tahminlerine daha fazla katılarak, Haziran 2016'dan Ağustos 2016'ya kadar süren anketler tamamlandı. Çelik fabrikasında sürekli olarak çalışan beş ayrı işyerinden toplam 100 işçi çalıştı. Islak ampul küre sıcaklığı (WBGT), fizyolojik gerilme (PSI) ve ısı stresi (HSI) endeksleri belirlenmiştir. İşçilerin verimlilik düzeyleri, iş yoğunluğu eğrilerine göre iş kapasiteleri ile farklı WBGT düzeyleri arasındaki ilişkilerin analiz edilerek ve öngörülen ortalama oylama (PMV) - verimlilik modeli kullanılarak değerlendirilmiştir.WBGT'nin en yüksek tahminleri Ağustos ayında, yüksek fırın bölgesinde ve 31,32 ± 0,8 ° C ve 31,34 ± 0,7 ° C ortalama tahminleriyle ayrı ayrı, sürekli döküm ünitesinde çarpıcı bir şekilde kaydedilmişken, en büyük HSI haddeleme tesislerinde % 137.83 ± 18.45 bir değer. Katılımcıların yaklaşık% 86'sı ısı dalgaları, kir ve gaz emisyonları nedeniyle yaz ortasında sıcak sıkıntıya maruz kalmıştır. Kalp atım hızı (r = 0.648 ve r = 0.517) ile birlikte, çekirdek vücut sıcaklığına (r = 0.725 ve r = 0.721 tek tek) sahip PSI ve WBGT indeksleri arasında kuvvetli ilişkiler saptandı. Bunlar, işçilerin sağlığı ve performansı üzerindeki ısı yükü etkisini değerlendirmek için en uygun endeksler olarak kabul edilir.

Anahtar Kelimeler : Isı yükü, Çelik fabrikası, Verimlilik, WBGT, HSI, PSI

Bilim Kodu **:** 928.1.065

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CONTENTS

Page

Page

Page

LIST OF FIGURES

LIST OF TABLES

Page

CHAPTER 1

INTRODUCTION

1.1. BACKGROUND OF THE STUDY

The Iron and Steel industry are recognized as a major economic force in Turkey, however, it is one of the most hazardous industries, where workers are continuously exposed to high temperatures during the eight hours work shift. They undergo high heat exposure during the various processes of steel production such as extraction, tapping, burning scraps, casting and melting. The specific environmental stress conditions found at iron and steel industries are radiant heat, air pollution, and noise, and the impacts of introduction to lifted heat levels may run from discomfort and productivity loss to serious health risks.

Taking this fact into consideration this study focused on working environment factors which have negative effect on workers' wellbeing and execution in different units at steel plant, where excessive heat on employees was determined in coke-oven plant, e.g. coke pushing all the way down to the end rolling. A coke cake leaves the retort at 1300°C as a purple hot metal ingot weighing one to two tons, and a plate heated to 1100-1200°C acts as a large source of heat. Then again, a jet of steel walking from the ladle having a diameter of 50-80 mm, a twine rod rising from a rolling mill at 800-900 °C and a flat rising from a section rolling mill are small -surface assets. Similarly, in some areas of the iron and the steel industry, humidity is higher than normal because of the hot rolling prepare and connected prepare steps water is utilized for cooling and for mechanical reasons. There has been considerable research addressing the consequences of some of the above conditions on human performance and physical comfort, either one at a time or both combined. Despite the efforts, detailed studies addressing the effects of working conditions on employee's performance in steel plants are lacking. Therefore, it has become essential to identify the locations and conditions in which heat exposure causes thermal discomfort on the employees, and take the necessary precautions to either avoid them completely by adjusting the working environment conditions or clothing accordingly, or to minimize workers exposure to the minimum possible and protect their physical and psychological well-being during their eight-hour shift.

A deep knowledge of the effects of working environment conditions on the overall performance of workers would assist to set up limits beyond which the performance of steel plants workers would be designated as degrading. This information would then further help to design a manual of rules and regulations for workers overall performance beneath normal, emergency situations and accident management conditions, since comfortable working conditions make the employees willing to use their full working capacity, in this way increasing productivity.

It is well established that thermal comfort and air quality both have significant impacts on workers' physical comfort and performance. According to the American Society of Heating, Refrigerating and Air-Conditioning Engineers ASHRAE Standard 55 [1], hot consolation is characterized as: "that condition of intellect which communicates fulfillment with the hot environment". Based on ASHRAE's recommendations, the zone of thermal comfort is defined as the range of conditions where 80% of people find the environment thermally acceptable. On a steady state, thermal comfort at low activity level is defined according to the following physiological conditions [2].

1. Range of internal body temperature 36.6 to 37.1°C.
2. Mean skin temperature between 33 and 34.5°C for man, and 32.5 and 35°C for women.
3. Local skin temperature varies according to body region, but it is generally between 32 and 35.5°C.
4. Temperature control is fulfilled as it were by vasomotor control of blood stream to the skin and it includes no sweating or shuddering present.

Heat stress is characterized as the whole of the heat generated by the body, also called metabolic heat, plus the heat obtained from the surrounding environment, such as air temperature, air movement, humidity, radiant heat, and clothes we wear. Heat stress happens when the body fails to control its internal temperature at the optimal range, and whenever this happens, it causes physiological stress and the body's counter-response is called Heat Strain. This process involves a myriad of physiological processes and chemical reactions leading to sweating, increased heart rate and core body temperature. According to the National Institute for Occupational Safety and Health (NIOSH) (Criteria for a Recommended Standard Occupational Exposure to Heat and Hot Environments) [3], core body temperature should not exceed 38°C and the average heart rate should not go beyond 110 beats per minute (bpm) during prolonged heavy work [4]. Normally, body temperature is kept at a constant level throughout our life. This is accomplished by the balance of heat produced by the body in the form of metabolic heat and the temperature of the surrounding environment. In cases when this balance is disturbed, other mechanisms such as sweating and shivering get involved to reestablish it, otherwise deep tissues get damaged and body enters a state of physiological stress.

1.2. STATEMENT OF THE PROBLEM

In the iron and steel manufacturing processes, particularly during the hot months of the year due to warmer atmosphere in addition to the heat radiated from molten material and hot surfaces of the cast, heat stress becomes one of the greatest issues faced by the workers.

Therefore, a better understanding of the phenomenon by continuous monitoring of the working environment and successfully managing it in order to prevent heat-related diseases and maintaining the optimal efficiency of the workforce, is an important priority for the industry. Among the many adverse effects of heat stress are physical discomfort, increase in physiological strain [5-8], decreased performance and productivity [9, 10], which may lead to increases in accident rates[11, 12] (Figure 1). Given the significance of the phenomenon, collecting and analyzing the results in order to identify the proper ways of reducing heat stress impact has been the focal point of our research.

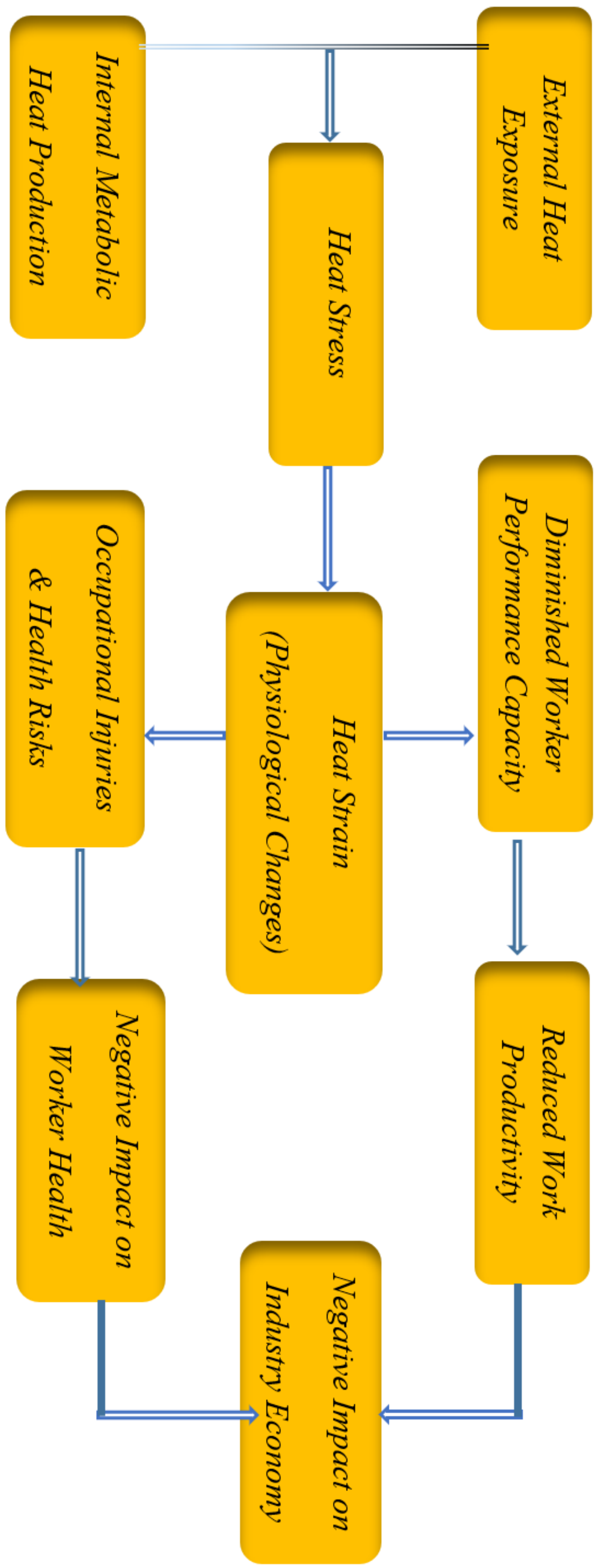


Figure 1.1.A schematic links between occupational heat exposure and comfort, health and productivity.

The risks of exorbitant heat exposure have customarily been studied in occupational settings incorporate out of doors domestics and staff in hot conditions, such as fire fighters, bakery pirate, farmers, construction workers, miners, boiler square alleviate, and works keep from and, numerous proposals were refreshed, including those on water utilization. [13]. The problem has been recently exacerbated by climate change and growing global temperatures. As a result, it is critical to quantify the heat stress load imposed on workers' body as it could have adverse effects on their ability to work, and cause a number of heat associated infections. Throughout the years, many indices have been developed and implemented by the industry to assess the extent of heat stress hazard to the employees, such as wet bulb globe temperature (WBGT), Heat Stress index (HSI) etc. To estimate the magnitude of the heat load, the six human heat natural parameters are used; air temperature (T_a), radiant temperature (T_r), air velocity (V_a), humidity (RH), clothing properties and the metabolic rate [14].

1.3. AIM OF STUDY

In this study, we have the following aims:

1. Establish the primary factors which contribute to workers' heat stress within the working environment.
2. Determine acceptable exposure time ranges to work in hot environment.
3. Evaluate the wellbeing chance from introduction to warm push.
4. Estimate and quantify the workers' productivity loss due to diverse levels of heat exposure during the working hours.
5. Provide valuable scientific evidence to advise the advancement of heat related controls and rules for heat anticipation and adaption in hot working environments.
6. To find out the levels of air pollution and its effect on workers' health in Kardemir steel plant.

1.4. OBJECTIVES OF THE STUDY

The most objective of this work is to survey the thermal environment conditions in a plant of iron and steel industry in Karabük (KARDEMİR), Turkey. This assessment will be made by a cross-sectional study involving a survey, experiments and statistical analysis. To achieve this goal, several steps were followed:

1. Surveying the workers at the industrial plant.
2. Experimental measurements.
3. Calculation of the thermal stress and strain indices.
4. Characterization of the thermal working environment, and its impacts on workers' productivity, according to the measured data.

To achieve the proposed targets, a few principal investigate questions rise::

1. What are the factors that influence the thermal working environment?
2. How can thermal environmental factors affect workers performance and comfort?
3. What are the most valid indices for evaluating heat load affect on workers consolation and execution in a steel plant?
4. Is there any relationship between work place environment and the productivity of the workers?
5. What are the methods that should be applied to decrease air pollution levels and improve the comfort sensation on the workers?

1.5. IMPORTANCE OF THE STUDY

The importance of this thesis arises from the fact that, there is lack of research exploring the impact of heat exposure on workers comfort and performance in Turkey, particularly in steel plants. In our case study, Kardemir iron and steel plant, higher workplace temperatures cause physical discomfort and a significant loss of productivity among the workers, especially during the hot summer season. Among the significant gaps in knowledge in this area, the following are the most important:

1. A need of significant examinations around recognitions of thermal working environment in different workplaces in KARDEMİR factory.
2. A need of information around work-related sicknesses and wounds which are related with heat presentation in steel industry.
3. A lack of specific occupational heat stress regulations in most industrial sectors.

Thus, this consider will advantage industries and laborers in numerous ways, such as progressing workers' wellbeing and efficiency, and as a result, economy In expansion, it'll give the industry, word related wellbeing professionals, and arrangement producers with prove that can be utilized in creating unused guidelines to make strides the chance recognition of delayed warm introduction, and diminish warm stress related danger within the work environment.

1.6. STRUCTURE OF THE DISSERTATION

This dissertation will fill many gaps in understanding and investigation of local heat presentation levels in Kardemir steel plant as described via wet bulb globe temperature (WBGT), Physiological strain (PSI), and Heat stress (HSI) indices of occupational heat stress and their negative suggestions on wellbeing and productivity of exposed workers, by comparing the work of a wide range of authors as well as providing crucial additional data obtained at the plant.

Chapter one provides background about the subject in arrange to get it the basic ideas behind thermal comfort, and the effect of heat on workers' productivity. It also expounds on the aims of the research. In chapter two, a review of past research as well as current knowledge that deals with thermal comfort and the thermal working conditions in different industrial sectors have been outlined. These studies also provide insights and guidelines for improving safety and health standards for workers within the setting of heat exposure and productivity loss. Chapter three includes the theoretical background about thermal comfort, human thermoregulation, and the concept of heat stress indices used to understand the plan and assessment of hot working situations. This is followed by fourth chapter which clarifies in detail the analytical side, explaining the research methodology and the data analysis. After finishing of the field work in all the chose zones, questionnaires were given sequential numbers before data entry. Information were entered and analyzed by utilizing SPSS version 20 whereby frequency tables were run and mean and standard deviation were determined. Likewise the correlation and regression analysis were utilized to measure the relationship between the variables (independent and dependent variables) and the strength of their relationship. Additionally, a more point by point depiction of strategies utilized to create the implies of anticipating execution misfortune within the heat has been detailed. The overall results of the study are discussed in chapter 5. Finally, conclusions, suggestions and certain regulations to be implemented for improving the working environment, safety, health standards and performance of workers in Karabük (KARDEMİR) plant are designed in chapter 6. Figure 2. shows the map of the thesis.

Table 1.1.The research framework.

The Research Methodology		
Theoretical	**Chapter 1** Introduction	• Background of the study • Statement of the problem • Importance of the study • Aim & objectives of the study • Research questions • Structure of the dissertation
	Chapter 2 Literature Review	Introducing the concepts of thermal comfort, heat stress indices, and excessive heat impacts on workers' health and productivity.
	Chapter 3 Theoretical Background	• Heat balance and heat exchange • Measurement of heat stress • Heat stress and strain indices
Analytical	**Chapter 4** Methodology and Research Design	• Questionnaire • Measurements • Productivity loss measurement • Data collection & analysis • Validity & reliability
	Chapter 5 Results and Discussion	• Data analysis and results • Discuss the results and compare them to other studies outcomes
Evaluation	**Chapter 6** Conclusion and Recommendations	Conclusion and a set of parameters to act as guidelines for the future.

CHAPTER 2

LITERATURE REVIEW

2.1. INTRODUCTION

The chapter focuses on effects of heat stress and its symptoms on employees working under high heat exposure and how it affects their health and productivity. The information reviewed here was taken from books, journals and other scholarly articles. This chapter has been prepared into four parts. Part one presents a review of the impact of heat exposure on a group of selected high-risk industrial occupations. Part two summarizes published studies on management of industrial heat for workers safety, health and productivity. Part three provides an overview of heat stress standards and guidelines. Finally, the fourth part includes a review of the occupational safety and health regulations in Turkey.

2.2. OCCUPATIONAL HEAT STRESS IN INDUSTRY

There are many adverse effects of heat stress as a result of working in hot situations, and they may lead into a number of illnesses, ranging from heat rashes to the devastating cases of heat stroke. Some of the health problems include dehydration, kidney failure, cardiovascular and respiratory diseases, failure of thermoregulatory system, and finally death [15]. Human body's thermoregulation involves a myriad of physiological mechanisms which are genetically encoded. Such mechanisms include both detection systems such as thermoreceptors, and mechanisms acting to cool the body when the physiological threshold is passed (thermoeffectors), such as sweat glands and vasomotor functions. However, the proper functioning of these systems is influenced by many intrinsic and environmental factors, such as ailments, when the patient is under medication, clothing, age effect, gender, pregnancy, physical activity, heat acclimatization, body mass index (BMI), body size, as well as body composition [16].

When the surrounding temperature comes to or surpasses body's center temperature (37 °C), a number of well-characterized acute physiological effects occur which pose various risks to our health [17]. After the core temperature increases 0.2-0.3°C above optimum, blood flow is diverted towards the skin, where sweating is initiated in order to cool the body. If the core temperature reaches 38-39°C, the risk of heat exhaustion occurs, and in the case when it passes 39°C mark, heat stroke may follow, leading to the failure of the thermoregulatory system. If the core reaches the temperature of 42°C, death becomes inevitable [18]. Some of the bad consequences include dehydration, heat fatigue, organ injury, kidney disappointment, debilitating of the safe framework, and an increased burden on respiratory and cardiovascular system. There are also indirect effects of high heat exposure at the work place, such as increased rates of accidents and psychological damage to the employee [19, 20]. In addition, it can cause irritation and anger, leading to spontaneous, uncontrolled actions in people who are working in hazardous occupations

In order to evaluate heat stress in a workplace, three variables must be taken into account: the environmental heat at the site, metabolic heat produced as a result of physical activity, and workers clothing [21]. On the other hand, environmental heat has four factors: air temperature, humidity, radiant heat and air movement. The main source of radiation heat is the sun in outdoor settings, but in some cases, it may come from certain processes involved in industrial plants, such as furnaces and steel mills. In addition, surface temperatures also affect human body by direct contact with them. This means that in certain situations, in addition to radiation, heat exchange by convection has to be counted as well [22].

Problems of heat stress are quite common in many industries, especially in Iron and Steel Mills, Forge shops, Glass and Ceramic Units, Bricks and Tiles Factories, Cements, Coke ovens, Laundries, Mines, Thermoelectric plants, and many others. There are many settings in these units where the ambient temperature is deliberately kept high because it is part of the process. Heat stress becomes very harmful for the workers especially during the hot summer season in melting and casting units, since on top of the high atmospheric temperature, the heat radiated from hot surfaces and molten materials at the site is added. Therefore, solving the problem of heat stress on workers of these industrial units necessitates continuous monitoring of the environment as well as workers' health state so as to better understand the phenomenon and find feasible solutions, since such working environments take a toll on both workers' health and productivity, as pointed out in a number of studies [23, 24].

There are various environmental factors that significantly influence worker productivity in many industries, and iron and steel manufacturing a typical harsh place where over the top heat presentation may be a major word related issue for worker. Many studies have already shown that the main factor of thermal stress in this industry is radiant heat from coke ovens and furnaces, especially during the hot, humid summer season [25]. The increased heat exposure also heavily affects workers' productivity by creating occupational physical and psychological health risks. Occupational heat stress transpires from several contributing factors acting both in isolated and/or synergistic manner [26]:

1. High ambient temperature and humidity that can happen in indoors as well as in outdoors settings. Indoors exposure can occur during certain processes, and it can expose individuals to temperatures which they have not normally experienced and are not acclimatized to, giving them no opportunity to recover during the period between shifts.
2. Intense and long working-hours increase the amount of metabolic heat in addition to the external one. One of the main challenges of the body is not only to acclimatize to external heat, but also get rid of excessive metabolic heat produced during strenuous physical activities such as the one involved in industrial plants, since during mechanical movements, more than 70-80% of the metabolic energy is converted into heat.
3. Another cause of heat stress is the protective clothing which is necessary in many industrial processes, since it impairs heat dissipation by sweat evaporation or convection [27].

Assessment of heat stress requires the use of indices which account for various effects such as metabolic heat, radiation heat or clothing effect. Through the years, a great number of such indices have been developed by researchers and presenting an exhaustive list of them is beyond the scope of this study. Since heat stress is the result of body's exposure to high heat, heat strain indicators are used extensively to monitor the physiological response during work in hot environments NIOSH 2013[28], OSHA 2015[29] . Some of the most common indicators are Core Temperature (T_r), Skin Temperature (T_{SK}), workers' Heart Rate (HR), as well as a composite index called Physiological Strain Index (PSI), developed by Moran et al [30].

According to NIOSH, the recommended exposure limit (REL) is defined as the level of sustainable heat stress under which workers may be continuously exposed without having any negative impact on their health (also called unacceptable strain), that is, the core body temperature should not deviate more than 1˚C from the optimal 37˚C for unacclimatized employees. For the acclimatized workers, the maximum limit under which they can safely perform their duties can reach up to 38.5˚C for expanded time periods. Another measure considered as exact by many researchers is the Intestinal Temperature (T_{re}), which can be measured by means of ingestible sensors which travel to the gut. The most important advantage of this method is its ability to accurately measure the core body temperature at the industrial site during actual working time periods [31, 32].

During working hours, employees are exposed to a combination of metabolic as well as environmental heat stress conditions, and as a result, experience different levels of physiological stress depending on the external factors and their body's response to them in arrange to preserve the balance. Therefore understanding the global heat stress extent on the workers, requires the combination of a number of heat stress indices.[33]

Changes in reaction to a specific heat strain indicator such as HR, T_{re}, or T_{SK} could be invaluable for preventing high heat strain in cases when environmental conditions are either difficult or impossible to assess. In addition, they are essential to measure physiological response to thermal stress in cases when a third factor other than environment and metabolic rate is included, such as clothing.

Dehydration is another important consequence of heat stress, and its rate varies both between individual workers, as well as working environments. Given its importance for maintaining a healthy physiology, it has been extensively studied through the years [34]. The main mechanism of water loss is through sweating, which depends heavily on the intensity and duration of the working process. Dehydration rate is determined by measuring the percentage of weight loss after a certain work process, and it has been found that a loss of two percent can cause a critical increment in center body temperature, decrease the sweating rate, decrease aerobic performance and elevate the heart rate.

2.3. MANAGING INDUSTRIAL HEAT FOR SAFETY, HEALTH AND PRODUCTIVITY

The relationship between productivity and work environment has been extensively studied since the beginnings of 1990s. Both field and laboratory research showed that chemical and physical factors present at the work site can have dramatic effects on occupants' health and performance, leading to decreased productivity. Conditions such as air quality, humidity and noise pollution at the site were determined to negatively effect workers' satisfaction and productivity [35].

However, small consideration has been given to the impacts of expanded heat exposure on employees' health. The effects have been recently compounded by climate change and global warming [36]. The need for further qualitative research on the physiological mechanisms involved in adaption to extreme heat are essential since they are either lacking or very sparse.[37, 38]. The health sector is lacking behind in studying, understanding and acknowledging the effects of environmental heat in common, and climate alter in specific on peoples' health, in particular those working in various industries [39, 40].

Increased heat exposure is not limited to workers' health only, but it drastically affects their productivity as well since a person exposed to high heat stress has to avoid heat accumulation and increased core temperature by either increasing the resting periods or decreasing the work intensity. There are a number of ways to decrease heat stress, such as by decreasing metabolic heat production or increasing heat exchange by means of evaporation, radiation or convection. The last three factors can be modified by means of engineering the working environment by increasing ventilation to bring in cooler air from outside, reducing radiant heat from its sources, using air conditions or shielding the workers from the heat. Heat stress bed basically beyond be administratively controlled through limiting the workers' exposure time by arranging the working and resting schedules accordingly. Such schedules will also reduce metabolic heat and enhance workers' tolerance to heat (acclimatization).

Even though most of the workers will acclimatize to their working conditions if appropriate measures are taken, a certain number of them will not, a condition called heat intolerance. Heat intolerance is due to many factors, some of them not fully understood, and a test should be used to determine it for each individual, especially after an unpleasant case of heat exhaustion or exertional heat stroke [40]. Additional measures should include establishment of a sensing system to evaluate the environment as well as provide cooling protective clothing such as air-cooled garments, wetted over garments, water-cooled clothes and cooling vests.

According to a study by Boles et al. [41], when the workers are physically fit and emotionally satisfied, their desire to work is higher and their performance increased significantly. In addition, they also emphasized that having an optimal working environment reduces absenteeism and increased workers performance, resulting in increased productivity. Other research has concurred with these results by showing that there are many positive effects of a proper working environment such as good machines and facilities designs, proper schedules etc., on workers' productivity [42].

According to [43] Sekar , the relation between work, the site, and tools and facilities, are an integral part of productive work. Therefore, the management which aims to maximize productivity by designing strategies to increase the workers' productivity needs to be focused on two areas: personal motivation and a good working environment infrastructure.

Joydeep Majumder et al. [44] conducted a study in Western India's ceramics industry and iron foundry in order to assess the differences in heat load and working environment conditions between these industries. They found that iron industry had a persistent hotter environment throughout the day. Moreover, this increased heat load had an impact on workers' productivity. Factors such as heat, humidity, metal dust, wielding fumes cause significant strain on workers, resulting in physical discomfort and reduced productivity [45]. The connection among temperature and relative humidity on worker productivity in automotive industry has been studied by Ismail, et la. [46], and their effect on the production rate is mathematically modelled, where the outcomes demonstrated higher estimation of relative humidity adds to higher of productivity.

Lee Taylor, et al. [47], studied the negative effects of passive exposure to a number of extreme phenomena such as cold temperature, extreme heat and hypoxia on cognitive function during simple and complex tasks and found them to be detrimental. In another setup, Ismail, et al. carried out a control study in a laboratory resembling an assembly line in automotive industry. They used the Taguchi method to assess the effect of temperature and found out that high heat followed by illuminant light and relatively high humidity levels have a negative correlation with workers' productivity rate [48].

In addition, Quiller et al., carried out a cross-sectional study on agriculture workers to estimate the relationship of WBGT and productivity [49]. To that purpose, they used linear mixed effects modelling and found an inverse correlation between WBGT and productivity. These results were corroborated by another study of Sudarshan at al., [50] who showed empirical evidence suggesting a significant decrease in workers' productivity with increasing environmental temperatures in India's manufacturing sectors. Additional proof on the financial expense of diminished productivity in higher environmental temperatures was given by Zander, et al. [51], who described work absenteeism and reductions in work performance utilizing a sample of 1726 workers amid the summers of of 2013-14 in Australia. They found that yearly costs were US$655 per individual, which speaks to a yearly monetary weight of around US$6.2 billion (95% CI: 5.2–7.3 billion) for the Australian team of workers. In order to minimize these negative effects and avoid probable incidents, Taufek, et al. [52], have suggested that employers should strictly comply with all the current regulations on workers safety. The negative effects of heat on mining workers were studied by Maurya et al.[53]. They also made a list of suggestions to improve productivity, work quality and employees' health status. Finding better solutions is paramount as projections show an increase in the frequency, duration intensity and severity of heat waves which will negatively affect workers' productivity. According to these estimations, by 2050 the work capacity may be reduced by as much as 80% in developing countries of mid-altitudes [54].

Also, various studies have demonstrated that workers' job satisfaction, their motivation, participation, performance and health status are fundamentally impacted by the psychological and sociological condition of the working atmosphere or organization they are part of [55]. An even more problematic case is when the workers are exposed continuously to hot environments which is added to their metabolic heat due to the physical activity. Such chronic exposures can lead to developments of health problems starting with skin rashes, heat cramps, heat syndrome, exhaustion up to the worst of all, heat stroke [56]. Sweating and the heat loss accompanying it by evaporation during strenuous physical activity is a powerful cooling mechanism. However, its effectiveness depends heavily on the environmental temperature, air speed, humidity, as well as clothing which reduces the cooling effect of evaporation. This means that for people wearing protective clothes, heat stress happens at lower temperatures and humidity as compared to those who do not [57].

In a study, a group of researchers studied the effects of working above the Threshold Limited Values (TLVs) in an Aluminum smelter. Data were measured with a focus on three variables: workers' oral temperature, average heart rate and the recovery heart rate. Oral temperature and the mean heart rate are indicators of good control of exposition to heat stress. The authors reached the conclusion that by decreasing the physical demands involved on manual crust breaking by using better engineering, will significantly reduce the strain on cardiovascular system as determined by the average heart rate and high recovery of heart rate [58].

A software created by Rabadi et al.[59], is utilized to assess the thermal comfort of people working outside. This is based on a method used to compute the Mean Radiant Temperature (MRT) at a steady state, and although it was originally meant to be used outside, it was modified to be used indoors as well. Modifications were made to include on mean temperature's calculations the effect of solar direct, diffused radiation as well as the heat emitted and radiated from the ground and the surrounding settings close to the subject.

For deeper analysis to better understand the impact of extremely hot environments on heat stress, Predicted Heat Strain (PHS) index used to measure thermal strain is very useful. It was originally developed to evaluate transition conditions in hot settings. Karin et al., [60] carried out a study to investigate productivity loss because of high heat using a thermo-physiological model dependent on physiological heat stress index (PHS). As mentioned before, another important empirical index used widely in many countries is WBGT, which stands for the heat stress under which an individual is exposed. It has been prescribed as a standard heat stress index based on ISO 7430.

Work at high environmental temperature, such as those above 35°C could lead to a number of health hazards in addition to loss of productivity. A study to determine the relationship between workers performance and temperature showed that a temperature increase by 1°C at the range of 25-32°C was accompanied by 2% decrease in work performance, but no change was observed for the range of 21-25 °C [61]. This study showed that after a certain threshold (25°C), workers' productivity starts to decline steadily with every degree increase in ambient temperature. There are many studies on the adverse effects of heat stress on occupation from many sectors such as construction and automotive industries [11, 62, 63]. A recent big study including 18 work places showed that 87% of workers experienced health issues due to heat stress within the hottest months of the year and nearly half of them detailed diminished efficiency as a result [64].

Other industries where studies on the [65]workplace have been carried out include mining [66], industrial workers [67, 68], traffic [69] , and agriculture [70], among many others. All the workers of these industries are exposed to different levels of heat stress coming from various sources such as radiant heat for those working outside, metabolic heat from physical activity, or furnaces and cupolas for those working in metal industries. As mentioned before, all these heat sources negatively affect the occupant's physical and mental health, leading to a significant decrease in productivity according to exposure scale.

In addition to individual studies, meta-analysis have also been carried out to better understand the effect of heat stress on workers' health and performance. [71] Such studies concluded that high heat has negative effects on workers' performance in general, and in a number of tasks in particular: perception, where increased periods of heat stress lead to reduced accuracy, cognition, where heat reduces cognitive accuracy but not its response time, and tasks involving psychomotor system, where high heat reduces accuracy but increases the speed.

Thermal factor is essential in determining optimal productivity, especially in cases involving strenuous physical work. According to a study conducted by Fisk [72], productivity increases up to 7% were measured for ambient temperatures of 20-24˚C. In contrast, productivity rate starts to decline after one hour of moderate physical activity in places where temperature is 32˚C. In order to decrease their core temperature and prevent adverse health effects, workers are always seeking thermal comfort by reducing their physical activities whenever they are faced by heat stress. This leads to a reduced work capacity and economic productivity [73]. Thermal environment therefore affects both, workers' physiological and psychological states, which in turn affect performance at work, and as a result decrease productivity. According to Ramsey [74] performance reduction may happen around the WBGT of 30-33˚C.

2.4. PRODUCTIVITY LOSS FUNCTIONS

To estimate productivity reduction for individual workers as a result of physiological heat stress, the methods of previous researchers working on population levels and using internationally agreed standards on breaks length and temperatures above stress threshold were strictly followed. We used only internationally recognized ISO standards. These international standards, based on previous physiological studies, use the Wet bulb globe Temperature (WBGT) as a basis. Worker's productivity is defined as the proportion of a typical working day during which an employee works under various heat conditions. The productivity of a worker for a certain work intensity is a monotonically decreasing function of the Wet bulb globe temperature between an upper and a lower bound, as shown in the graph in Figure 2.1.

Investing in health and safety at work should be seen as a valuable investment rather than liability. The European Association for National Productivity Centers [75] issued a memorandum in 2005 entitled "The High Road to Wealth", looking at productivity from the perspective of value creation. According to the report, several factors summarized in figure 2.2 contribute to this value creation.

Among those factors, one of the most essential is health and safety at work. Since human capital is a must for a future-oriented development, companies are in an increasing need of highly-qualified, efficient and highly-motivated workers, willing to actively contribute to new challenges at technical and organizational level. Thus, to keep their workers physically and psychologically fit, appropriate working conditions are essential for highly productive, competitive, and innovative future enterprises [76].

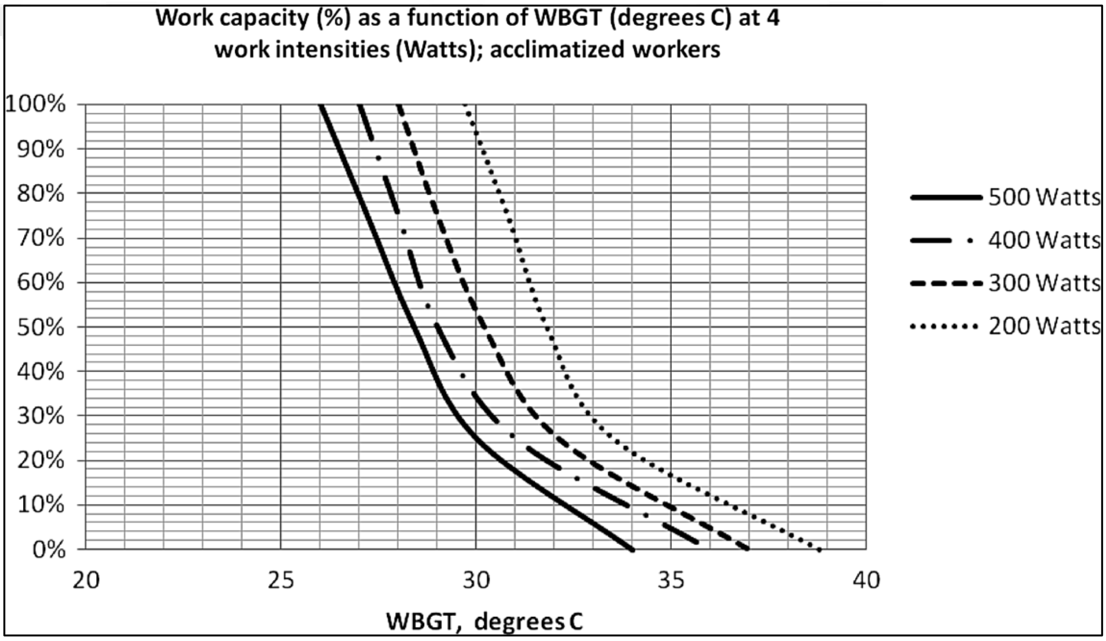


Figure 2.1.Association between work capacity and WBGT for 4 work intensities [77].

As it was stated inside the preceding section, numerous studies had been completed to understand the impact of environment on human performance and job satisfaction. However, those findings were often specific to some particular investigations and concerned with isolated components of the physical working environment. Thus, in a study to understand the impact of working environment on intermittent workers, it was determined that an increase of 1°C in the ambient temperature causes an increase in heart rate of 1 beat per min (bpm) [78]. Therefore, if thermal stress is not kept within a certain range, various symptoms and health problems starting from mild disorders such as rushes and burns to lethal conditions are inevitable.

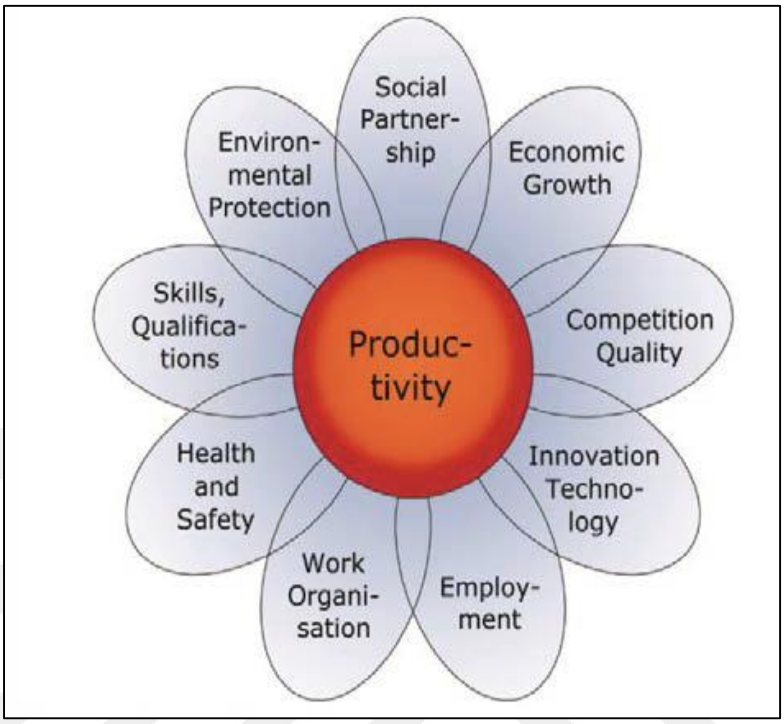


Figure 2.2. Productivity and its contributing factors [79].

One of the most important elements figuring out the overall performance of a company of any scale or affiliation is its productivity. As has been already established by the studies mentioned before, heat cause physiological stress of various degrees, especially in people under strenuous physical activities. However, heat effects are not limited to these people, but also to those carrying out other tasks due to inherent physiological states of each person. Due to this, studying the relationship of thermal environment and personnel' productivity is some distance extra complex than it appears to be since it depends on many environmental elements along with air temperature and velocity, relative humidity, radiant temperature, and individual factors such as clothing, physical activity and health status. As a result, the impact may vary widely from person to person [80].

In addition to the factors above, a study has shown that companies which report organizational problems have also more performance problems which are many times related to their working conditions such and lack of facilities such as manual handling of materials, lack of work motivation, problems with machines, and lack of training or hot environment. Accordingly, in a study in an Indian factory, the temperature was determined to be 46ºC during the hot summer months. Other complaints were about noise and dust in the work place. As a result, company managers receive various complains from their employees, among them arms and hands soreness, back pain, fatigue neck and upper body pain being the most common [81].

Toxicological research has added further evidence on the adverse effects of heat on workers. Some studies have shown that increased temperature helps in absorption of toxic materials into the body, however, most of the body of research on this area has been performed on animals so more studies are required to determine the exact mechanism on humans [82]. Climate change has added an additional layer of complexity as well as a more urgent need for better understanding of the impact of heat on humans. In addition to the updated research, this criteria text file includes more resource for worker and employer training [83].

A study investigating the effects of heat stress on workers cognitive performance in casting plant showed that heat stress severely impaired cognitive function leading to a number of errors, which became worse as the task duration was elongated, showing a clear inverse relationship between exposure time and cognitive function. In addition, heat stress can also affect other cognitive functions such as short-term memory, long-term memory and decision making among many [84].

Rowlinson et al. [85] carried out a study and devised a methodology to develop a number of tools for optimizing work-rest regiments and work pace using PHS model for management of heat stress in construction industry of Hong Kong. They found that the environmental thresholds calculated by the PHS model based on the data at hand are 2-3°C-WBGT above those of TLV and ISO 7243 reference.

The effects of clothing on workers have also been studied in many industries, but the focus has mostly been on their thermal effects, such as their impact on heart rate or changes of core temperature cause by different cloth types and performance decrease when workers are wearing personal protective clothes (PPCs). To quantify the impact of PPC on metabolic load, European Union undertook an ambitious project named THERMPROTECT whose point was to give authoritative data and device models to evaluate heat and cold stress on workers. The real piece of the investigation included exploratory estimations and questionnaire to accumulate the important data, are utilized to confirm the systematic methodology, which gives valuable way to deal with realistic implementation in protecting apparel requirements for moderate thermal radiation environments [86].

2.5. HEAT STRESS STANDARDS AND GUIDELINES

Many standards for measuring and estimating the effects of heat stress on human physiology and psychology have been devised and used throughout the years, both internationally and for individual countries. However, the most widely-used ones are the list of threshold limit values (TLVs) used for measuring the effects of chemical substances and bodily sellers, and the biological exposure indices (BEIs) to measure the biological effects, both of them issued by the American Conference of Governmental Industrial Hygienists (AGGIH) [87]. International scientific bodies such as National Institute for Occupational Safety and Health (NIOSH) [88] have also formulated standards for monitoring heat stress and its accompanied occupational health risks, as well as safe limits of exposure. Their main aim is to prevent core body temperature from reaching and surpassing the limit of 38°C since the health risks increase drastically after this threshold. We will present a short list of some of these standards below.

2.5.1. ISO 7243

ISO 7243 sets different WBGT threshold temperatures for the cases of acclimatized workers who perform various physical activities in a workplace. Thus, a WBGT threshold of 28°C stands for a moderate activity generating 234-360 Watt heat, whereas for 25°C it stands for heavy workload producing 360-468 Watt under ow air velocity. The assumptions of this standard are that the employees are physically fit for the activity they are carrying out, they are healthy wearing standard summer work clothing with thermal insulation values of 0.5 Clo., where 1 Clo. = 0.155 $m^2 \cdot K \cdot W^{-1}$ [89].

2.5.2. ISO 7933

Entitled Ergonomics of the Warm Environment: an explanatory assurance and translation of warm stretch utilizing calculation of the Anticipated Warm Strain (PHS) to estimate the rate of sweating and core temperature that will develop in the body during certain working conditions ISO 7933 [90]. Its main aims are to determine heat stress in situations that may cause substantial increase in core temperature or dehydration, and also to determine the time ranges in which physiological strain under a certain temperature will be tolerable by the body.

2.5.3. ISO 8996

ISO 8996 is entitled "Ergonomics of the Warm Environment: Assurance of Metabolic Heat", was final reexamined in 2004. It indicates the suitable strategies and ways to degree and decide metabolic rate beneath certain natural conditions, survey the working hones, and indicates strategies for deciding the metabolic rate in a working environment, evaluating working hones, and calculate the enthusiastic fetched of a certain movement [91].

2.5.4. ISO 9886

ISO 9886 stands for "Ergonomics: Assessment of Warm Strain by Physiological Estimations", is used to determine the appropriate methods to measure physiological strain on humans based on four parameters: core and skin temperatures, heart rate and body mass after a certain task [92].

2.5.5. ISO 9920

ISO 9920, moreover known as "Ergonomics of the Warm Environment: Estimation of Warm Separator and Water Vapor Resistance of a Clothing Outfit", is the standard for determining the appropriate methods to estimate thermal characteristics such as resistance to dry heat and evaporative heat losses when the workers wears certain clothes based on a number of predetermined values of ensembles, garments and textiles [93].

2.6. CONTROLS

Given the severity of the impact of heat exposure, a number of factors need to be addressed to manage and minimize health risks related to heat stress. Since the phenomena does not depend on singe factor, multiple controls need to be taken into account, some of which are explained in more details below.

2.6.1. Elimination/Substitution

Among many possible ways in this category, these are some of the most effective ones:

1. Work ought to be scheduled to keep away from the hottest part of the day.
2. The design of buildings where hot processes take place should be done in ways that allows good air flow by through windows, shutter and appropriate roof design, creating "chimney effect" for heat dissipation.
3. Building light-colored roof and external cladding can also significantly reduce internal temperature by reflecting the incoming sun light.

2.6.2. Engineering

Engineering is an integral part of a proper work place maintenance, and two of the most effective measures to be take on this direction are:

1. Air circulation in the work place should be enough to allow evaporation by sweating, one of the body's primary cooling mechanisms. Also designing the buildings to allow higher air velocity should be a priority. This can be further enhanced by adding fans or bringing in cool air from chiller units.
2. Erecting barriers to prevent heat radiation from units where a lot of heat is produced. They could be of different nature, such as highly reflective aluminum sheets or tarpaulins. If possible, ductworks and hot pipes should also be insulated or lagged to prevent heat radiation on the workplace.

2.6.3. Administrative Controls

In addition, administration can take measures to improve the resting and recuperation of workers by using simple adjustments to make the life of workers easier:

1. Equipped get entry to cool, palatable consuming water is a crucial necessity.
2. Building cool and comfortable rooms within the factory for workers rest and recuperation after working for a certain period of time is important. Studies have shown that recuperation occurs far more quickly when rooms are air-conditioned. These rooms may be simple having just air conditioners, clean water supply and comfortable sitting places. In cases of field work where mobility is essential, even simple shade or large umbrellas are enough to provide shelter from solar radiation.
3. More effective work-rest regimes may become necessary in cases where engineering controls are not sufficient. To effectively determine these, indices such as WBGT, PHS or TWL are essential to determine the optimal work-rest regimes.
4. Regular training sessions of the workers to make them aware of the symptoms associated with heat stress and enable them to determine their onset.
5. Self-determination or pacing of the work to meet the situations.

2.6.4. Personal Protective Equipment

There are a variety of available personal protective equipment (PPE) such as cooling vests with vortex tube air cooling, or phase change cooling inserts are useful in many situations. However, caution must be used when using iced or chilled water since it can lead to blood vessel contraction, in this manner reducing the cooling effect of the garment.

2.7. A PROFILE OF OCCUPATIONAL SAFETY IN TURKEY

The main regulatory entity of occupational health and safety in Turkey is Presidency of Institute of Research and Development of Occupational Health and Safety, also known as "ISGUM", which is under the supervision of Ministry of Family, Labour and Social Services. Occupational Safety and Health Law (OSH, No. 6331; 2012) is applicable for all kinds of jobs and all workplaces, for both, public as well as private sectors around Turkey. According to ISGUM's website, the mission of OSH Law is to regulate rights, obligations, responsibilities, authority and duties of workers and employers to ensure work safety as well as improve the conditions in the future. In addition, they also aim to prevent disease and accidents, physical and mental problems related to workplaces. This law also sets the standards and defines the terminology related to the working environment, such as risk, disease and accidents related to work, safety units and the ways to respond to certain situation by health professionals [94].

OSH law puts the responsibility of ensuring a safe workplace on the employer, who has to take precautions to avoid real and potential risks, continuously educate the workers and enforce the safety measurements on them, embrace the latest safety measurements available, and reduce the exposure of workers to the possible minimum to dangerous substances either by using protection measurements, or whenever possible, replace them with less dangerous ones. The law also sets a list of duties on the employee and recognizes their right to abstain from work when imminent and serious danger is involved. A more complete list with full details of rules and regulations, obligations and responsibilities of the parties involved can be found in ISGUM's website [95].

CHAPTER 3

THEORETICAL BACKGROUND

3.1. HEAT BALANCE AND HEAT EXCHANGE

It is extremely important for the core body temperature to remain within a very limited range of 37°C (98.6°F) ± 1°C (1.8°F) in order for it to function properly and be in a healthy state. Any deviation from these limits leads to physiological stress. However, as mentioned before, maintaining this range requires regular exchange of heat among human body and the surrounding temperature. The quantity of heat to be exchanged is a complex variable involving many factors, the most important of whom are the metabolic heat which is produced by the body, which varies from one kcal per kilogram of body weight per hour ($5kcal.kg^{-1}$) during rest, to $5kcal.kg^{-1}$, during moderate to high physical activity in industrial workstations. It is also expressed in watts (W), which for the above cases would vary from or 1.16 to 7 W. The second component of heat exchange is the heat gained from the surrounding environment, if any. The rate of this heat exchange is the function of HR, T_{SK}, T_a, V_a, T_r, and characteristics clothes worn by the person during the occasion. There is also the component of respiratory heat loss, but in normal situation it is ignorable, except during strenuous work in dry environment, where heat loss as evaporation becomes really significant (figure 1). Below, a simplified version of heat balance equation according to standard international (SI) unit system will be provided.

3.2. HEAT BALANCE EQUATION

One of the fundamental equations used to measure heat stress is the Basic Heat Balance equation expressed as follows:

$$S = (M - W) \pm C \pm R \pm K - E \qquad (3.1)$$

In other words, heat storage in the body is the difference between heat production and heat loss. The symbols are:

S represents the exchange in body heat content,
$(M - W)$ is an expression representing the total heat produced by metabolism minus that generated by external work performed by the subject.
C represents the convective heat exchange in $(W.m^{-2})$ units
R stands for radiative heat exchange also in $(W.m^{-2})$ units.
K represents the conductive heat exchange in $(W.m^{-2})$ units.
Finally, E stands for heat loss through evaporation in $(W.m^{-2})$ units.
In order to solve the above equation, a number of measurements have to be performed, including M, water-vapor pressure P_a, T_a, V_a, and MRT.

3.3. MODES OF HEAT EXCHANGE

There are three main ways of heat exchange between humans and the surrounding environment, as shown in figure 3.1 namely evaporation, convection and radiation as shown in figure 3.1. There is a fourth one as well, that of conduction, but it does not play any crucial role in workplace environment, except for very brief periods when workers come into contact with tools, machines, walls, floor or any other surrounding, or when they are in supine position or come into contact with water [96]. Equations used in heat exchange calculations used for seminude subjects and workers wearing the conventional long trousers and long-sleeved shirt are applicable for both, the metric units as well as the old English system. Their units are expressed in kcal*h^{-1} for the “standard man” who is defined as a person weighting 70 kg (154 lb) and a total 1.8 m^2 (19.4 ft^2) surface area of the body. In this study, only the standard metric system (SI units) are used, and for employees who deviate from the standard, the appropriate correcting factors will be applied. The equations representing each component of heat exchange in SI units as well as their detailed descriptions are presented in the following subsections.

3.3.1. Convection (C)

This is an algebraic equation representing the standard person who, as explained above, is wearing the conventional long trousers and long-sleeved t-shirt during work. The equation is expressed as:

$$C = 0.65V_a \times 0.6(T_a - T_{SK}) \quad (3.2)$$

Where V_a represents the air motion and, T_{SK} represents the mean weighted skin temperature of the person which is usually assumed to be 35°C. In the case of T_a being greater than 35°C, the value $(T_a - T_{SK})$ will be negative, and as a result, there will be a gain in body temperature from the surroundings. If T_a is smaller than 35°C, then $(T_a - T_{SK})$ will be positive, so heat will be lost to the environment by means of convection.

3.3.2. Radiation (R)

In reality, radiant heat exchange should be expressed as the difference between T_w and T_{sk}, raised to the power of four $(T_w - T_{sk})^4$, but an accurate approximation used for the cases of workers wearing a single-layer clothing ensemble generally in use is as follows:

$$R = 6.6(T_w - T_{SK}) \quad (3.3)$$

Where T_w represents the mean radiant temperature of the solid surface surrounding the subject expressed in °C and $T_{sk}$is the mean weighted skin temperature, as explained in the previous section.

3.3.3. Evaporation (E)

Heat loss through evaporation is a function of many variables due to the complex nature of the phenomena. It is expressed as:

$$E = 14V_a \times 0.6(P_{sk} - P_a) \quad (3.4)$$

Where (V_a) represents the air motion, whereas (P_a) and (P_{sk}) stand for the water vapor pressure of the air in working surroundings and the that of the wetted skin at skin temperature, respectively. Therefore, evaporation can also be expressed as the function of air motion and the difference between ambient water vapor pressure and skin water pressure. For the standard person, P_a is measured in mmHg and P_{sk} is assumed to be 42 mmHg or 5.6 kPa.

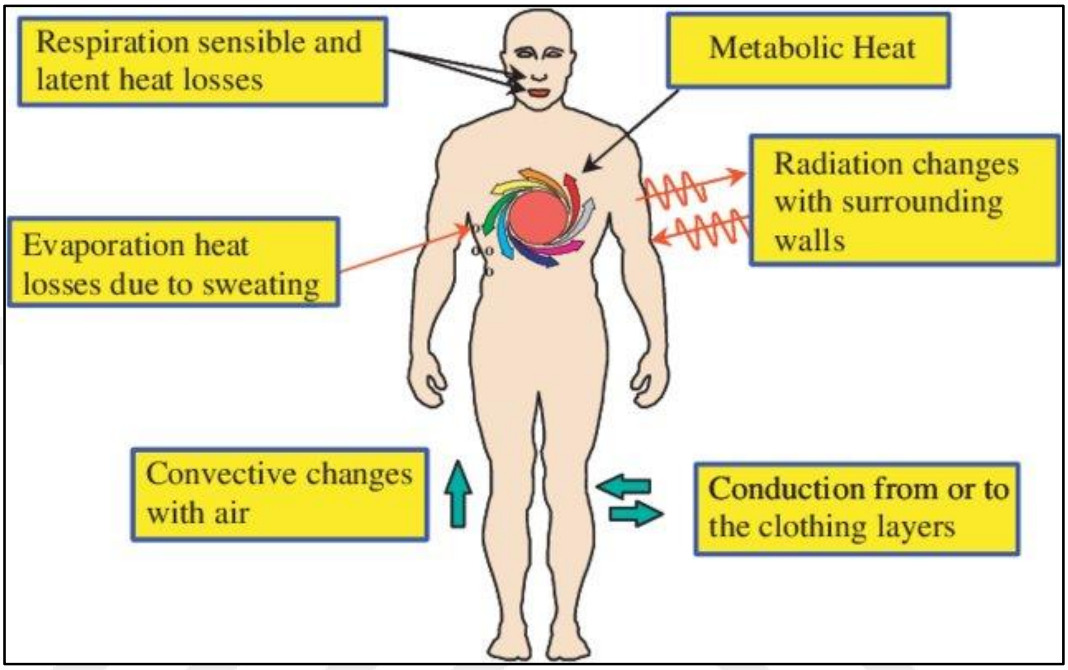


Figure 3.1.Heat exchange of the human body.

3.3.4. Conduction (K)

The phenomenon of conduction stands for heat exchange whilst the challenge is in direct contact with the surrounding environment and there is a temperature difference between them. As stated before, generally conduction is ignored due to its almost negligible effects, but there are a number of special cases such as ice vests or personal clothing with liquid cooling system when it becomes significant. The algebraic expression for conduction is:

$$K = kA(T_1 - T_2)/L \quad (3.5)$$

Where k represents the thermal conductivity dependent on the chemical and physical properties of the objects. A stands for the zone of contact included in heat conduction measured in m^2 and L stands for the distance between the two objects coming in contact. T_1 and T_2 represent the temperatures of the hotter and cooler body respectively. The above equation has been reorganized to represent heat conduction from a person to an object as follows:

$$K = kA\left(T_{sk} - T_{object}\right)/L \tag{3.6}$$

Where T_{sk} is the skin temperature, and T_{object} is the temperature of the object which is made contact with.

3.4. EFFECTS OF CLOTHING ON HEAT EXCHANGE

Clothing is an indispensable part in modern working places as it serves as a barrier protecting the vulnerable tissues of the workers against the harsh environmental conditions, be it hot or cold temperature, as well as physical assaults such as moisture and abrasions, and even radiation in certain occupations. As stated before, since all calculations for heat exchange through convection, radiation, evaporation and conduction are based on the "standard person", corrections need to be applied for the cases of deviation from that standard. One of the correction factors involves clothing when it deviates from the standard single-layer option. This correction should take into account among others, the cases when clothing involves two or more layers, its permeability, and the material it is made of.

One such correction involves the clothing efficiency factor (F_{cl}) which corrects for dry heat exchange and has no dimensions. Some researchers have suggested that the corrections of the Recommended Alert Limits (RALs) and Recommended Exposure Limits (RELs) reflect F_{cl} for a number of metabolic and environmental heat loads and three clothing outfits [97]. The single-layer clothing assemble is used as the background factor for any comparison involving the clothing factor. According to the convention, when clothing is double-layered, RAL and REL should be decreased by 2°C (3.8°F). For the case of an ensemble which is partially impermeable to air or water vapor, or heat reflective ones, RAL and REL should be decreased by 4°C (7.2°F). These deviations show that RAL and REL are not settled completely for any kind of working environment and condition, are mostly left to the judgment of the people involved. In cases when the ensemble is impermeable to vapor and air, WBGT is not an appropriate index to measure the heat stress from the ambient. Instead, a more accurate measurement that of dry bulb air temperature (T_{db}) should be used. Whenever the T_{db} surpasses 20°C (68°F), workers pulse rate and core body temperature measurements are required. In addition, Intrinsic clothing insulation (I_{cl}) which is a measurement for thermal resistance is expressed in the units of meter square per watt (m^2K/W) where one such unit is equivalent to 6.45 Clo. A summary of I_{cl} values for different clothing ensembles is shown on table 3.1

Table 3.1.Clothing adjustment factors for types of clothing (TLV corrections) [97].

Clothing type	WBGT correction
work garments (long sleeve and pants)	0
cloth (woven material) coveralls	0
Double layer woven apparel	3
SMS polypropylene coveralls	0.5
Polyolefin overalls	1
restricted use vapour-barrier overalls	11

3.4.1. Clothing Permeability and Evaporative Heat Loss

An essential thing of clothing is the fact that heat transfer through evaporation inversely and linearly correlated with the thickness of the clothing ensemble. To measure this, the moisture permeability index (i_m) is used, which is a dimensionless unit between the lower value of zero for completely impermeable clothing ensemble to air or/and vapor, and an upper limit of 1, when vapor and moisture can pass easily through the fabric into the surrounding environment without any impediment.

Table 3.2. Clo. Separator values for ordinary clothing outfits [97].

	I_{cl}	
Clothing ensemble	**Clo.**	**M^2°C W^{-1}**
Underpants, coveralls, socks, footwear	0.70	0.11
Underpants, blouse, pants, socks, footwear	0.75	0.115
Underpants, shirt, coveralls, socks, footwear	0.80	0.125
Underpants, shirt, pants, mild jacket, socks, footwear	0.85	0.135
Underpants, shirts, pants, smock, socks, shoes	0.90	0.14

Table 3.3. (continued)

Underpants, brief-sleeve undershirt, blouse, pants, light jacket, socks, footwear	1.0	0.155
Underpants, short-sleeve undershirt, blouse, pants, coveralls, socks, footwear	1.1	0.17
long underwear blouse and bottoms, heavy jacket, pants, socks, shoes	1.2	0.185
Underpants, short-sleeve undershirt, blouse, pants, light jacket, heavy jacket, socks, footwear	1.25	0.19
Underpants, brief-sleeve undershirt, coveralls, heavy jacket and p+ants, socks, shoes	1.40	0.22
derpants, brief-sleeve undershirt, pants, mild jacket, heavy jacket and pants, socks, footwear	1.55	0.225
Underpants, brief-sleeve undershirt, pants, light jacket, heavy quilted outer jacket and overalls, socks, shoes	1.85	0.285
Underpants, short-sleeve undershirt, pants, jacket, heavy quilted outer jacket and overalls, socks, shoes, cap, gloves	2.0	0.31
long undies blouse and bottoms, heavy jacket and pants, parka with heavy quilting, overalls with heavy quilting, socks, shoes, cap, gloves	2.55	0.395

3.5. BIOLOGIC EFFECTS OF HEAT

The biological effects of heat are numerous, and still purely understood. a number of research have already been carried out in various industries, and many are still continuing. In the sections below, we attempt to give a short summary of the problem since part of this research is involved with the topic.

3.5.1. Physiologic Responses to Heat

Figure 3.2 is a simplified scheme showing the major systems of the body involved in detecting and dealing with heat stress. To put it simply, our body is embedded with receptors monitoring itself and the surrounding environment in real time, which in turn signal their effectors. Effectors receive the information and are able to differentiate signal from noise in a way still not understood. Once the signal is detected, it is sent to some central integrators that serve as central units generating a "thermal alert", activating the necessary mechanisms in place to deal with excessive heat. As stated before, the main mechanisms for the body to rid itself of excessive heat are sweating and vasodilation to extremities during heat stress, and vasoconstriction during cold shock. Studies have shown that the control center for heat stress is mostly in hypothalamus, though there are other minor locations which change for different species [98].

3.5.2. Acclimatization to Heat

Whenever employees get exposed to hot working environments, the conventional signs of heat stress such as increased heart rate, higher-than-normal core temperature, nausea, headache and even extreme cases of heat exhaustion become apparent within a brief time period [99]. However, as the working experience increases, workers start to show what is termed as heat acclimatization, where the person gets used to heat ranges higher than normal people. Full acclimatization is a slow process which can happen in cases when workers are exposed for short periods of time to elevated temperatures on a daily basis.

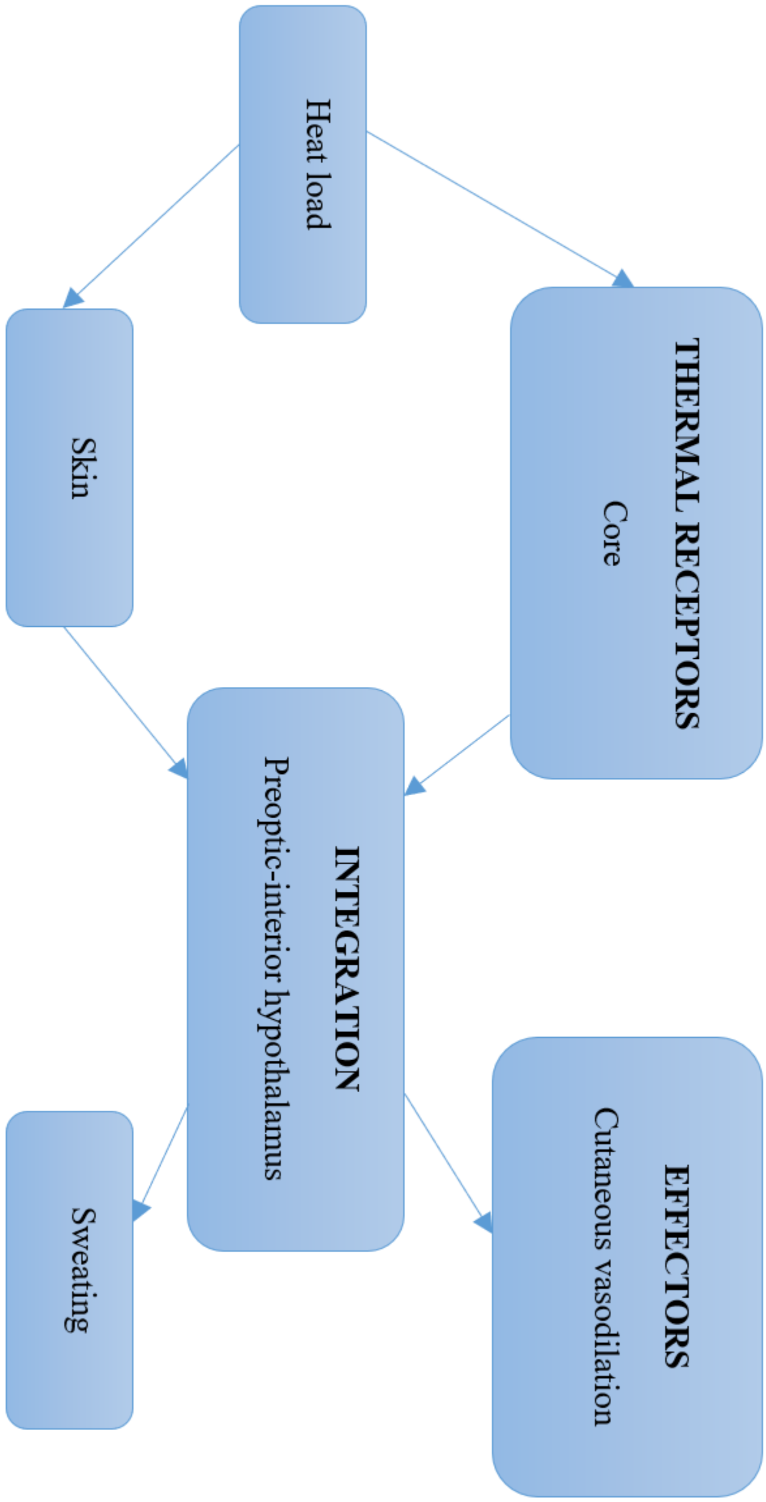


Figure 3.2. Physiological response to heat load.

No continuous heat exposure for 24 hours is required, which in fact is harmful for the subjects' health status since the unacclimatized workers will find it extremely difficult to replace the water they lose by sweating. Studies have shown that the minimum daily exposure time for heat acclimatization is as it were 2 hours broken down into two intervals one hour each. However, the acclimatization level depends heavily on the fitness state of the individual, their previous exposures as well as their general health state. For instance, a workers doing only indoor light work even in hot environment will not accomplish the necessary level of heat acclimatization for working in an outdoor environment exposed to the continuous radiative heat of the sun, or in the same indoors environment but more demanding physical work. Better aerobic fitness reduces heat stress by providing partial acclimatization due to the adaptation to metabolic heat produced during physical exercise. In addition, studies have shown that fitter individuals show a decreased incidence of illnesses or injuries related to heat exposure in work places [100].

3.5.3. Other Related Factors

The risk of heat-related medical conditions is increased by a number of factors, some of them not as well-studied as the rest. The best-known ones are environmental factors such as humidity, high temperature and direct exposure to sun light. In addition, heat radiation sources inside the plant such as furnaces and ovens add more burden to the above-mentioned factors. Their effects are further compounded by lack of air conditioning and ventilation. However, this is not the end of the story as there are many factors related to the individual worker's physiological and psychological state, such as:

1. Age
2. Sex
3. Body Fat
4. Drugs
5. Individual's genetic variation

3.6. HEAT-RELATED ILLNESSES AND WORK

Heat-related illnesses may be common in certain workplaces even when the working conditions are within the ranges of regulations due to the workers physical state being a risk factor itself. These ailments are mostly common in environments with high humidity; elevated temperatures, high radiant heat sources and in operations involving physical contact with hot surfaces. Some of the outcomes of prolonged heat exposure are heat exhaustion, cramps and even heat exhaustion. This happens as a result of the body's mechanism to deal with intense heat by diverting blood circulation from vital organs such as brain into extremities to cool itself and cause sweating. As a result of decreased blood flow to the brain and muscles which carry out the heavy workload, the workers physical and mental abilities are weakened, leading to serious consequences if the necessary steps to get out of the dangerous situation are not undertaken [101].

3.7. MEASUREMENT OF HEAT STRESS

Heat stress, as mentioned before, can be defined the state when the combination of heat from a person's metabolism, environmental factors and the clothing ensemble exceeds the body's optimal temperature beyond a certain acceptable range. This situation is recognized as an emergency situation by the body and the appropriate mechanisms to deal with it are activated immediately, a process called heat strain. Heat strain is defined as the physiological response which attempts to transfer the excessive heat from the body of the subject to the environment by increasing heat loss [102]. However, depending on the environmental condition and the physiological condition of the employee, these mechanisms may not always succeed, leading to serious health consequences and even death. Therefore, measuring and quantifying heat stress is essential. To do so, measuring both climatic and physical elements within the operating environment and knowledge their effect on human physiology through the use of appropriate and measurable indexes becomes paramount. Table 3.3 shows a summarized list of the both environmental and non-environmental factors contributing to heat stress.

Table 3.4.Factors that contribute to heat stress.

Environmental Factors	Non-Environmental Factors
Air Temperature Air Velocity Radiant Temperature Relative Humidity	**Personal Factors** - Clothing - Wellbeing Condition - Acclimatization - Hydration **Work Factors** - Metabolic Heat - Work Rate (Light/Moderate/Heavy)

There are a number of conditions in using these indexes which are essential for getting accurate and reproducible results, such as:

1. It is important to use appropriate thermometers to cover the correct range of the temperature to be measured.
2. The time of measurement should be beyond the time necessary to stabilize the thermometer.
3. The sensing element of the thermometer should be brought as near as conceivable to the protest or region of intrigued so as to get the most accurate measurement.
4. Whenever temperature is measured under radiant conditions, such as outdoors under the sunlight, the sensor of the thermometer should be shielded in order to get accurate measurements.

3.7.1. Heat Radiation

The sources of radiant heat can be grouped into natural, such as solar heat, and artificial, such as radiation in industrial plants of metals, ceramics, glass, etc. There are a number of instruments in use to measure artificial radiation, the most common being radiometers and black globe thermometers. Their characteristics differ substantially from pyrheliometers or pyranometers which are utilized to degree sun powered radiation. In any case, for measuring warm stack from sun oriented and infrared radiation on specialists, the dark globe thermometer is the foremost widely-used instrument nowadays.

3.7.1.1. Artificial (Non-solar or Occupational) Radiation

The basic design of a typical back globe thermometer is made of two parts: a 6-inch hollow black-colored copper sphere for absorbing the incident infrared radiation (0.95 emissivity), and a sensor which could be either a thermistor, a thermocouple or a partial immersion thermometer with a glass rod filled with mercury. The sensing element of the sensor is placed at the center of the hollow sphere for maximizing the accuracy of radiation measurement.

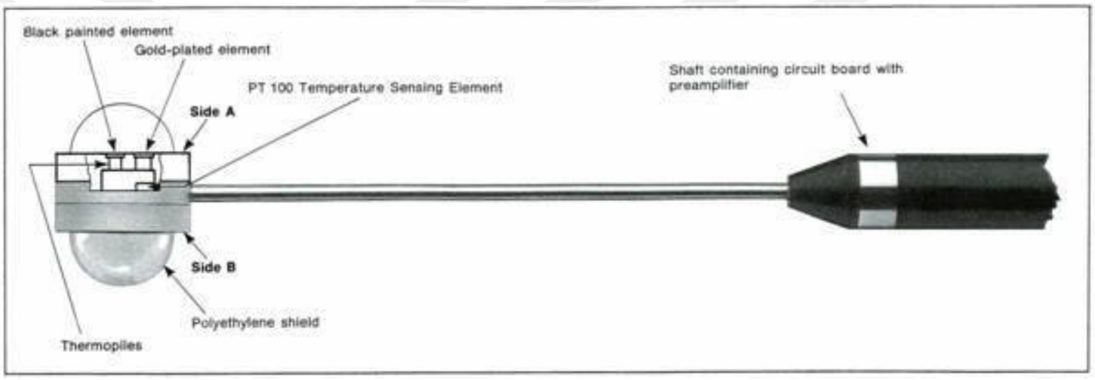


Figure 3.3.The design of Vernon Globe Thermometer and its parts [103].

The most commonly utilized gadget for measuring and measuring word related brilliant heat is the Vernon Globe Thermometer (figure 3.3). It is also recommended by NIOSH for measurements of Black Globe Temperature (T_g) and it is commonly referred to as the “6-inch black globe” [103]. These instruments exchange heat with their surrounding environment by means of convection and radiation, and when it is stabilized, the heat exchanged by radiation becomes equal to that exchanged by convection. The time it takes for the thermometer to stabilize and conversion of black globe temperature to the mean heat radiant temperature (MRT) are both functions of the globe size. It takes 15-20 minutes for a standard 6-inch globe to stabilize, whereas the time for a small 1.65-inch globe is about 5 minutes. The most thermometer of choice for the industry and the one recommended by experts is the 6-inch one, but recently smaller versions have started to be used more frequently and have become commercialized. Despite these differences, the principles for both thermometers are the same [104]. Figure 3.3 demonstrates the varieties of anticipated globe temperature as a function of the diameter of the globe thermometer. The temperature measured by the black globe thermometer, air velocity and its temperature are all used to calculate the mean radiant temperature by the following equation:

$$MRT = T_g + 2.42V_a(T_g - T_a) \tag{3.7}$$

Where the meaning of each of the above symbols were explained in a previous section.

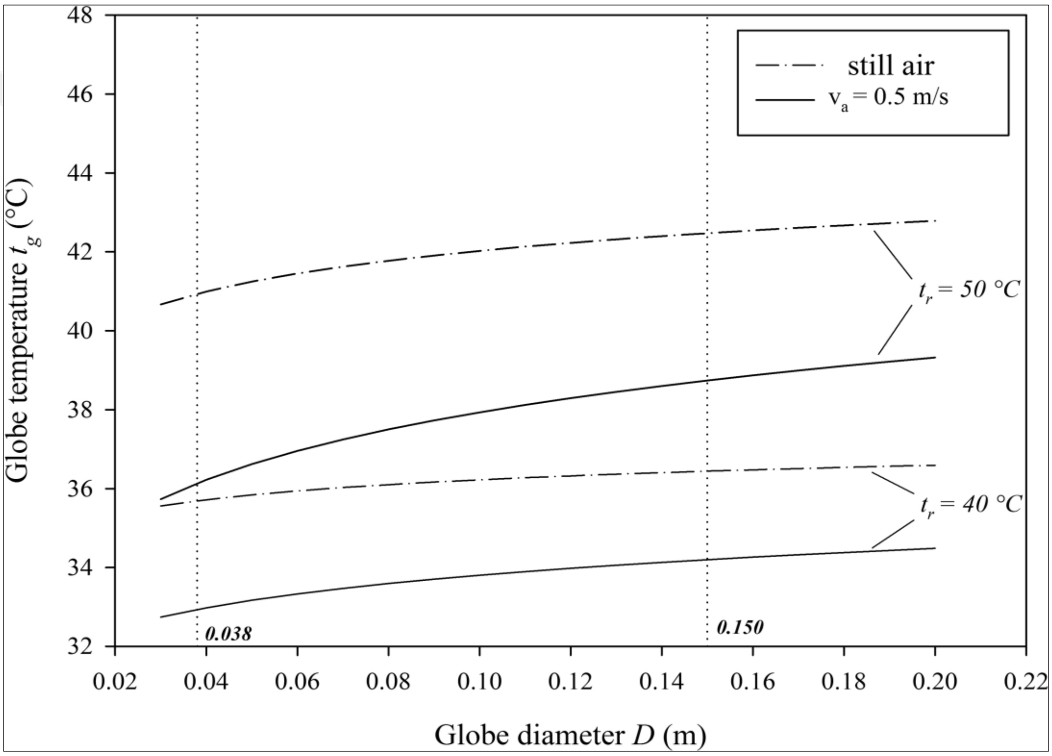


Figure 3.4. Examples of the varieties of anticipated globe temperature as a work of the distance across of the globe beneath common and forced conditions [104].

3.7.1.2. Natural (Solar) Radiation

Natural radiation can be classified as reflected, coordinate and diffuse. Coordinate radiation is the one coming directly from the solid angle of the disk of the sun without any barrier between the source and the target, in this case the worker. On the other hand, diffuse radiation, also known as sky radiation, stands for radiation that is reflected and scattered through the hemisphere after shading the strong point of the disk of the sun. At long last can be defined as the solar radiation which is reflected from the water or the ground. Therefore, the total solar heat load is obtained by summing all the above radiation types and correcting for the clothing ensemble of the worker and their body position during the measurement [105].

3.7.2. Psychrometric Chart

The psychometric chart is a summarized graphic representation showing the relationship between wet bulb temperature dry bulb temperature, vapor pressure, dew point temperature and the RH. Such a standard graph is shown in figure 3.3 [106]. This graph is very useful since information about any two of the variables mentioned before can be used to find the value of the unknowns. It should be noted that when RH reaches the value of 100%, the values of dry bulb, wet bulb and dew point temperatures all become equal. These charts are especially useful in determining and assessing indoors thermal temperature where solar radiation heat is almost negligible.

3.8. PREDICTION OF METEOROLOGICAL COMPONENTS

The National Air Quality Monitoring Network, the agency in charge for assessing the air quality in Turkey, has been running 249 Air Quality Monitoring Stations by 2016 around the country. The results of the stations are deposited and published on [107] on a continuous basis to make the sharing of this critical piece of information accessible for all those concerned. The network provides daily measures of a number of critical parameters on air quality, especially pollutant concentrations and distributions around the country.

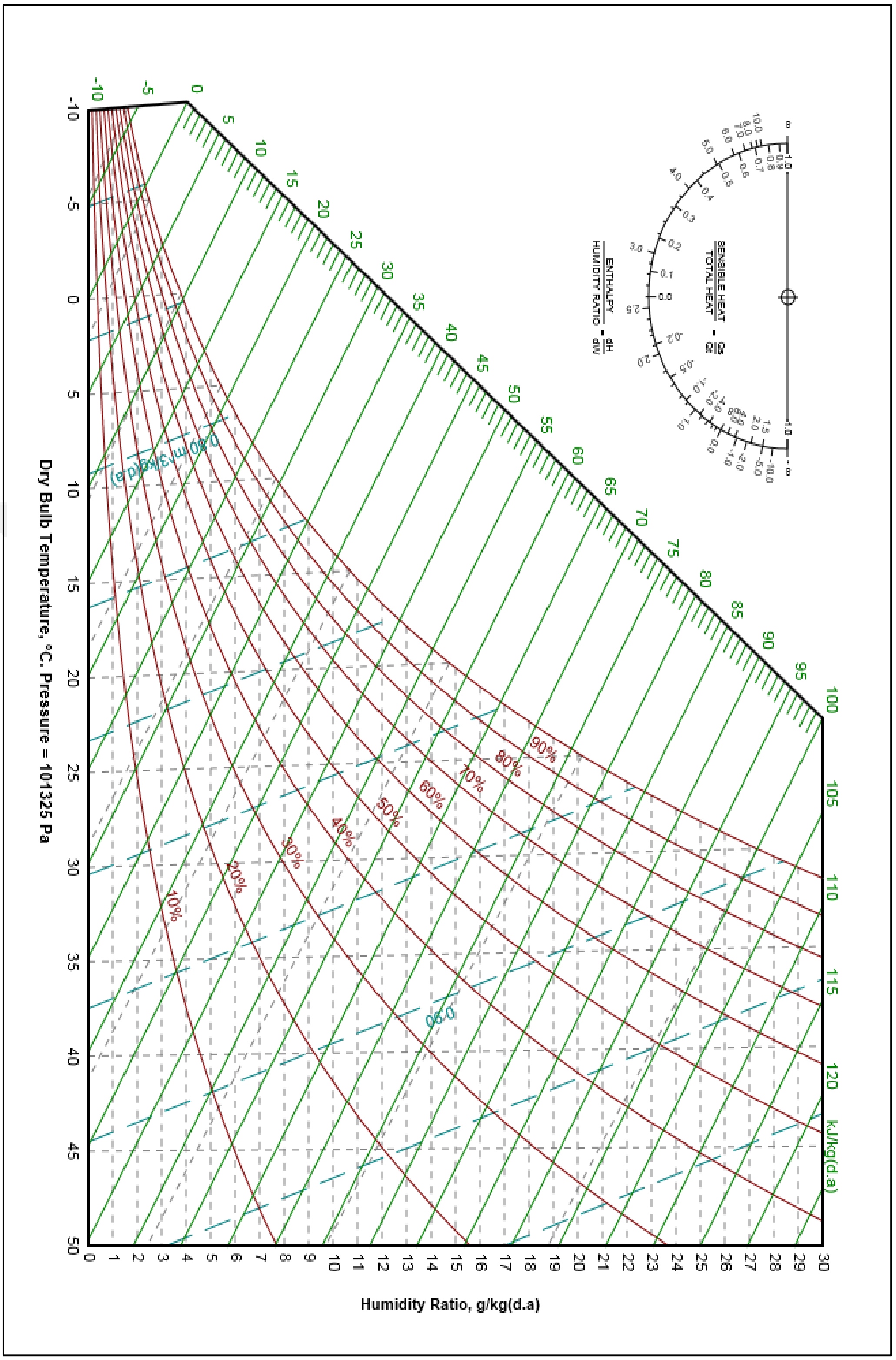


Figure 3.5.Standard psychrometric chart [106].

In addition, other parameters include air temperature, wind speed, visibility, dew point temperature and humidity. These information can be utilized to assess the heat load of working environment for outdoor jobs in industrial plants, and sometimes even indoors ones. Both actual as well as extrapolated data can be used to predict the wet bulb globe temperature, a critical index whose importance was explained previously.

3.9. METABOLIC HEAT

As mentioned in the previous sections, the total heat stack on the human body is the sum of metabolic heat produced by the body and the environment with all its components. Every physical activity costs a certain amount of energy which is measured by the metabolic heat (M) and makes an important fraction of the balance between body and environment. The value of M can be measured as well as estimated by other factors. A certain activity's energy cost has two components: the energy used to do the actual work, and the energy released as heat into the body and the surroundings. During physical work, muscle tissues' efficiency is in the range of 20%, with the rest being released as heat. If there is no external physical work, the total heat load of the body is almost equal to the full metabolic vitality turnover, so M can actually be equated with the total metabolic energy turnover [108].

3.9.1. Measurements of Metabolic Heat

There are two main ways to determine metabolic heat, namely by direct and indirect calorimetry.

1. For measuring the metabolic heat by coordinate calorimetry, the subject is put in a calorimeter which is closed chamber encompassed with circulating water. The heat released by the human body increases the temperature of the surrounding water, and the temperature changes of that water is used to calculate the amount of energy released at that period of time. As may be guessed by the procedure, this technique is of limited use in industry and other occupational studies due to its practicality, the expensive price of the necessary equipment and the fact that it is very time consuming [109].
2. In contrast to the direct method, the indirect approach is based on measuring the rate of oxygen consumption by the subject. Studies have shown that each litter of oxygen consumed by a standard subject results in the release of 4.8 kcal (5.6 W) of metabolic heat. The procedure involves either an open or a

closed circuit procedure. There is another more indirect method for measuring the metabolic heat based on a linear relationship between oxygen consumption and HR. However, caution should be displayed since the linearity does not hold for the cases when HR approaches its maximum values, because even though the pulse rate starts to level off, the rate of oxygen intake continues to raise. Another factor to be taken into account is the fact that linearity also changes from individual to individual leading to large variation in metabolic heat estimation [110].

3.9.2. Estimation of Metabolic Heat

As can be guessed from the procedural explanations in the previous section, both direct and indirect measurements of metabolic heat are limited in time and scope. They can be used only for activities involving short periods of time and require devices for measuring the volumes of oxygen and carbon dioxide consumed and produce within a certain time period. However, in order to measure the metabolic rate of a subject by using HR, a mathematical equation linking these two variables has been derived. According to ISO 8996 [91], there is a proportional relation between HR and metabolic rate under a number of assumptions, such as a thermo-neutral ambient and mental stress-free subject. Their relation under these assumptions is as follows:

$$HR = HR_0 + RM(M - M_0) \tag{3.8}$$

Where HR represents the subject's heart rate per minute, HR_0 stands for the resting heart rate in thermal-neutral environment, and RM stands for the increase in heart beat rate as a result of physical activity. M is metabolic rate expressed as $\left(\frac{W}{M^2}\right)$ and M_0 stands for the resting metabolic rate $\left(\frac{W}{M^2}\right)$ when the subject is not doing any physical activity.

In addition, RM varies according to the maximum work capacity (MWC) and the subject's maximum heart rate (HR_{max}) as shown in the equation below:

$$RM = \frac{HR_{max} - HR_0}{MWC - M_0} \tag{3.9}$$

In this case, MWC and HR_{max} can be calculated equations 10-12 where A represents the person's age and P their weight in kilograms.

$$HR_{max} = 205 - 0.6A \tag{3.10}$$

$$MWC = (41.7 - 0.22A)P^{0.666} \quad \text{(for male subjects)} \tag{3.11}$$

$$MWC = (35.0 - 0.22A)P^{0.666} \quad \text{(for female subjects)} \tag{3.12}$$

Based on equation 8, the value of M (W/m^2) can be calculated as follows:

$$M = \frac{HR - HR_0}{RM} + M_0 \tag{3.13}$$

3.10. PREDICTED MEAN VOTE (PMV) AND PREDICTED PERCENTAGE OF DISSATISFIED (PPD)

Fanger's equation is used to assess natural thermal environments [111]. For this purpose, two indices are essential, that of PMV and PPD (ISO 7730:2005) [112]. PMV index is used to measure the mean score of a group of people who vote on the scale of heat in a working environment. This is called a bipolar phenomenon involving a thermal feeling scale ranging from too hot to too cold. This scale has a scoring scale of 7, starting from +3, which represents very hot, +2 for hot, +1 for slightly hot, 0 for neutral temperature, -1 for slightly cold, -2 for cold and -3 for very cold. In summary, zero represents neutral working environment, the positive scale hot, and the negative scale cold working conditions.

The equation for calculating PMV is long and involves many variables, as represented below:

$$PMV = [0.303e^{-0.036M} + 0.028]\{(M - W) - 3.9E^{-8} f_{cl}[(T_{cl} + 273)^4 - (T_r + 273)^4] - f_{cl}\, h_c(T_{cl} - T_a) - 0.305[5.37 - 0.007(M - W) - P_a] - 0.42[(M - W) - 58.15] - 0.0173M(5.87 - P_a) - 0.0014M(34 - T_a)\} \tag{3.14}$$

The variables are: M stands for metabolism, W represents the mechanical work, P_a is for the partial pressure of water vapor in the air, T_a stands for air temperature, f_{cl} is the clothing area factor, T_{cl} is for the surface temperature of the skin covered by cloth, T_r represents the workers' rectal temperature, lastly h_c is for the heat transfer by convection coefficient. The meaning of all these variables have already been mentioned in the previous sections of this chapter.

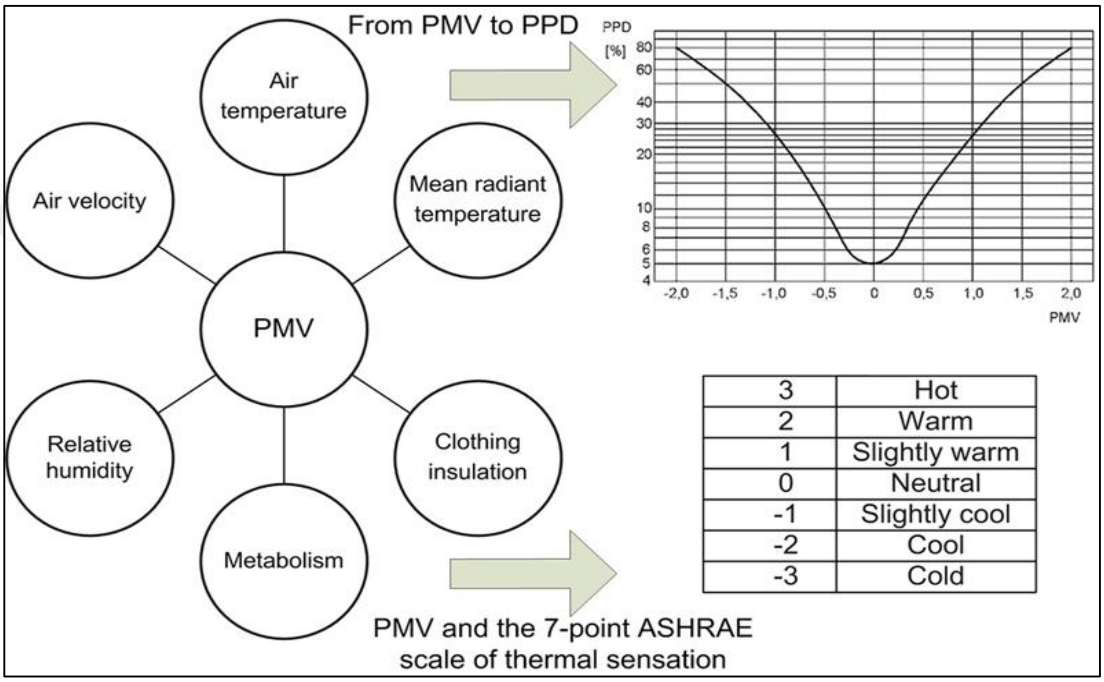


Figure 3.6.The PMV scale [112].

PMV is also used to estimate the number of people who are feeling uncomfortable by excessive hot or cold temperatures and it can be incorporated in the PPD index [113]. This index uses the voting score to estimate the number of people who voted for either hot (score 1 to 3) or cold (score -1 to -3) [114]. The subjects' thermal dissatisfaction is determined mathematically by using the following equation (15).

$$PPD = 100 - 95e^{-\left(0.03353PMV^4 + 0.2179PMV^2\right)} \quad (3.15)$$

A graphical representation of PMV vs PPD is shown in figure 3.5.

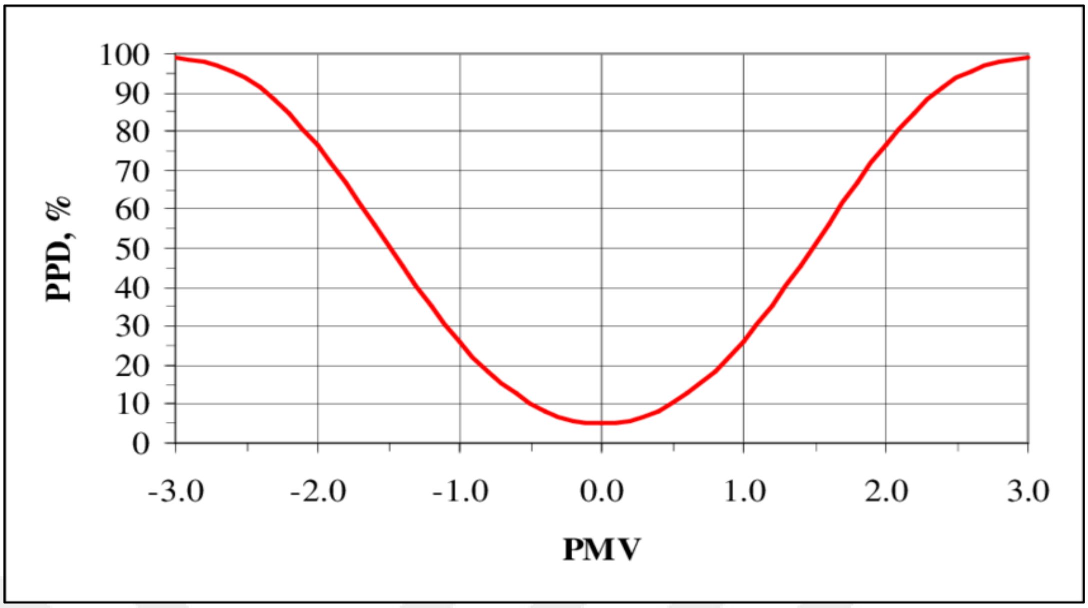


Figure 3.7.The relationship between PMV and PPD [113].

3.11. INDICES FOR ASSESSING HEAT STRESS

A heat index can be defined as an integrative value taking into account the cumulative effects of a number of basic parameters in a certain environment. Its value normally varies with the thermal strain experienced by each individual worker as each person has different parameters deviating from the standard. Through the years, researchers have come up with a number of useful models, standards and indices to assess the respective working environments and protect the workers involved from heat stress.

For any index to be approved and applicable in a certain setting, a number of conditions must be fulfilled first (Table 3.4):

Table 3.5.Main requirements for globe and natural wet bulb thermometers for the evaluation of the WBGT index [89, 115].

	Globe		**Natural wet bulb thermometer**	
	ISO	**ACGIH**	**ISO**	**ACGIH**
Shape	Sphere	Sphere	Cylinder	—
Diameter	1.50 cm	1.5 cm	0.6 ± 0.1 cm	—
Thickness	As thin as possible	—	—	—
Measurement range	21–121°C	−6 to 102°C	4–39°C	−1.2 to 49.0°C

Table 3.6. (continued)

Accuracy	21–51°C: ±0.6°C 49–118°C: ±2°C	±0.6°C	±0.5°C	±0.5°C
Mean emissivity	0.94	=	1.0	=
Length of the sensor	=	=	3.0 ± 0.5 cm	3.0 ±0.5 cm
Response time	As short as possible	26 min minimum	=	=

1. It must be accurate and feasible for a wide range of metabolic as well as environmental conditions where the workers may find themselves.
2. It needs to cover all the factors involved in heat stress, such as metabolic heat, clothing factor, environmental stress, etc.
3. The measurement of the index should be as realistic to the nature of the work it is supposed to assess as possible, ideally without any interference with the work process.
4. The limits of exposure should be within the ranges of physiological and psychological limits of the workers, assessing and reflecting the health risk and safety they are supposed to measure.

According to their rationale, heat indices can be classified into three groups:

1. Rational indices are those based on calculations using the heat-balance equation.
2. Empirical indices are those based on subjective and objective strains.
3. Direct indices are the ones based totally on direct measurements of certain variables in the working environment.

In this study, a number of heat stress indices, particularly wet-bulb globe temperature (WBGT), heat stress index (HSI), and physiological heat strain (PSI), were assessed and validated, and finally, an index was introduced as a valid index.

3.11.1. WBGT-Index

WBGT is one of the most wide-spread indices for heat-stress assessment and management. Its application to industry is formalized under ISO 7243 by NIOSH. In addition, the European standard for maximum levels of WBGT exposure for various working intensities are shown in table 3.5.

The main property of WBGT is its components: It combines the values measured from natural wet bulb temperature and globe temperature in addition to the air temperature at the working site, and as a result it counts for the most the three main heat transfer phenomena, namely radiation, evaporation and convection [116]. The different versions of the index for different settings are shown below:

Without solar radiation: $$WBGT = 0.7T_{nw} + 0.3T_g \quad (3.16)$$

In case of solar radiation: $$WBGT = 0.7T_{nw} + 0.2T_g + 0.1T_a \quad (3.17)$$

Where: T_g stands for black globe temperature (fig.3.6) measured by a globe of a diameter 15 cm (figure 3.6), and T_{nw} represents the natural wet bulb temperature. Both of them are measured in the units of degree centigrade.

Table 3.7. Prescribed greatest WBGT presentation levels at diverse work power and rest/work proportions for a normal acclimatized worker wearing light clothing [116].

Metabolic rate course (work escalated)	**(light work) WBGT (℃)**	**(medium work) WBGT (℃)**	**(heavy work) WBGT (℃)**	**(very heavy work) WBGT (℃)**
Continuous work, 0% rest/hour	31	28	27	25.5
25% rest/hour	31.5	29	27.5	26.5
50% rest/hour	32	30.5	29.5	28
75% rest/hour	32.5	32	31.5	31
No work at all (100% rest/hour)	39	37	36	34

Figure 3.8. Official WBGT instrument according to ISO 7726 and ISO 7243. [116].

3.11.2. Heat Stress Index (HSI)

The heat stress index is another useful index for assessing the heat stress. It takes into consideration the human heat balance and was created by Belding and Hatch [117]. The index is calculated by the following equations:

$$HSI = \frac{E_{req}}{E_{max}} \times 100 \quad (3.18)$$

$$E_{req} = M - R - C \quad (3.19)$$

$$R = 4.4(35 - MRT)V^{0.6} \quad (3.20)$$

$$C = 4.6V^{0.6}(35 - T_a) \quad (3.21)$$

$$E_{max} = 7V^{0.6}(56 - P_a) \quad (3.22)$$

As can be seen by the equation, there are many variables which we have come across in the previous sections. M represents the subject's metabolic rate as w/m^2, C represents the energy exchange by means of convection again in w/m^2, MRT stands for mean radiant temperature measured in ℃, T_a stands for workplace dry temperature(°C), V means air velocity in m/s, and P_a represents water vapor pressure in the air, measured in mb.

3.11.3. The Physiological Strain Index (PSI)

The Physiological strain index (PSI) was first developed by Moran et al. [118]. This index measures the subjects' heart rate and body temperature, and as a result, makes possible a real-time assessment of the physiological stress experienced by workers on a scale 0 to 10. It integrates and evaluates the joined effect of two crucial systems, namely thermoregulation and cardiovascular. This index does not involve as many variables as the others, and its derivation is shown by the following equation:

$$PSI = 5\left(T_{re,t} - T_{re,0}\right)(39.5 - T_{re,0})^{-1} + 5(HR_t - HR_0)(180 - HR_0)^{-1} \quad (3.23)$$

Here $T_{re,o}$ and $T_{re,t}$ represent the subjects' rectal temperatures during resting and working periods, respectively, while HR_0 and HR_t stand for heart rate under the same conditions.

3.12. AIR QUALITY

Besides water, food and shelter, clean air is one of the very basic necessities for the continuation of life on earth. Since the beginning of the industrial revolution, and especially after World War II, air pollution has gained catastrophic dimensions due to the increase of pollutants from industry and increasing population size around the globe. As a result, the problem of protecting air quality by taking the necessity measurements to protect life on earth has turned into a hot topic since 1960, when the real impact of air pollution started to be understood. As a result, The United Nations Conference on Environment and Development (UNCED) [119], designed and adopted the Framework Climate Convention which emphasises the need for protecting protecting the atmosphere by reducing air polution. Other conferences such as United Nations Conference on Human Settlements in Istanbul clearly defended the same provisions.

As a result of a number of such conferences since, the technology for better control of particulate matter released on atmosphere have improved significantly by using electrostatic precipitators, scrubbers or bag filters. Bag houses are one of the most widely-used controlling approaches used in steel plants due to their stringent criteria and lower cost as compared to others. Currently, the main emitters of SO_x and NO_x gases are integrated steel plants, thermal power plants and sinter plants. There has been a surge in technologies for reducing sulphur dioxide emissions, but currently their cost is very high. Despite these, there are a number of approaches currenlty in use. One of them involves the usage of coal containing low levels of sulphur in coke ovens, and studies have shown that coke desulphurization can cause up to 80% reduction in SO_2 emissions in steel plants. Another very effective though very costly approach is the introduction of desulphurisation in waste gasses in sinter plants. There have also been designed a number of effective approaches for reducing NO_x emissions, such as usage of staged burners [120]. Others not mentione dhere are very expenssive for the moment and not widely-used.

3.13. PRODUCTIVITY IMPACTS

the most center of this study is the loss of productivity due to the workers' heat exposure in their working environment. This loss is estimated by using two well-establied methods from previous studies. The first approach assesses the relationship of work intensity, extreme WBGT and the workers ability to work under these conditions. This method is under the standards of ISO 7243 for acclimatized people [121].

Theoretical outcomes were then compared with our survey data. The second approach is that of a widely-used theory that the employees productiveness can be expected as a feature of anticipated mean vote (PMV) index utilized in production industry with the aid of using a plynomial regression evaluation which offers 3 unique regression models which predict employees' productivity for heavy, moderate and light tasks [122].

The main reason for selecting PMV is its property of combining the effects of clothing ensemble, variables of the thermal environment, and the nature of the job being performed into a single thermal index. Its equation is shown below:

P_H=83+21.64 PMV- 9.53$(PMV)^2$+0.91$(PMV)^3$ (3.24)

PMV= (0.303$e^{-0.036M} + 0.028)L$ (3.25)

Where P_H represents the productivity value for heavy workload and the PMV index predicts the mean response of a larger group of people according the ASHRAE thermal sense scale. L represents the thermal load that's described because the difference among the internal heat production and the heat loss to the actual environment for a person at comfort skin temperature and evaporative heat loss by means of sweating on the actual activity level.

CHAPTER 4

METHODOLOGY

4.1. LOCATION AND CLIMATE OF STUDY AREA

4.1.1. An Overview of Karabuk Iron and Steel Plant

Turkey is one of the top 10 crude steel producers in the world, and has since 2012 cemented its place as the 8th leaving behind Brazil and Ukraine. However, the plans of the country are to be the fifth in the near future, putting the country on the same group with China, Japan, USA and India, therefore making investment on this industry a top priority. Turkey has nearly 150 steel production factories scattered around the country. Turkey in addition has created a well-educated and skilled workforce on this particular industry, the majority of them coming from universities and technical vocational schools. Many university programs are also focused on engineering, such as mining, materials, metallurgy and mechanical engineering department, all promising a bright future for the country on this direction.

One of the Major Players in Iron and Steel producers is Kardemir plant, which is an acronym for Karabük Demir Celik Fabrikalari, which in English is translated as Karabuk Iron and Steel Works. It plant started production in 1937 and was operated as a public company for 58 years until its privatization in 1995. One of the most important aspects of Kardemir is the fact that it is the only manufacturer of rails and heavy profiles, not only in Turkey, but the region as well. Kardemir is located in Karabuk city, in the black sea region of Turkey, a distance of about 200km north capital Ankara. The steel plant covers an area of 36,000 m^2, 30,000 m^2 area of which is outdoor space and employs 3800 workers. The factory works continuously round the clock in three shifts of eight hours each (figure 4.1). The climate of Karabuk is subtropical humid with humid and hot summers, and cold, wet winters. Its exact geographical coordinates are 41°11′55″N 32°37′35″E. A detailed climacteric overview of Karabuk is shown on table 4.1.

Figure 4.1.Kardemir iron and steel factory.

4.1.2. Description of Process

The process of steel manufacturing requires both, large amounts of energy and natural resources to be carried out. In some countries, energy makes up a very significant proportion of steel production, reaching up to 40% of the total cost. Therefore, finding ways to decrease the energy cost and make the process more efficient is of paramount importance and a subject of intensive research. The process of making steel is very elaborate and beyond the scope of this thesis. However, we will provide enough information in order to make our points of research clear. Integrated steelmaking process has three main phases (figure 4.2).

1. Reduction: Ironmaking
2. Refining: Steelmaking
3. Shaping & Coating

Table 4. 1.Climate data for Karabuk.

Month	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Year
Record high °C (°F)	22.1 (71.8)	24.8 (76.6)	32.5 (90.5)	34.9 (94.8)	37.0 (98.6)	40.5 (104.9)	43.6 (110.5)	44.1 (111.4)	40.8 (105.4)	37.2 (99)	25.8 (78.4)	23.7 (74.7)	44.1 (111.4)
Average high °C (°F)	7.0 (44.6)	10.1 (50.2)	15.3 (59.5)	20.2 (68.4)	25.3 (77.5)	29.0 (84.2)	32.1 (89.8)	32.7 (90.9)	28.0 (82.4)	21.5 (70.7)	14.2 (57.6)	8.6 (47.5)	20.33 (68.61)
Average low °C (°F)	−0.8 (30.6)	0.3 (32.5)	2.8 (37)	6.6 (43.9)	10.1 (50.2)	13.7 (56.7)	16.2 (61.2)	16.2 (61.2)	12.7 (54.9)	8.8 (47.8)	3.5 (38.3)	0.7 (33.3)	7.57 (45.63)
Record low °C (°F)	−13.9 (7)	−13.4 (7.9)	−9.2 (15.4)	−3.3 (26.1)	0.1 (32.2)	4.6 (40.3)	8.9 (48)	9.1 (48.4)	4.5 (40.1)	−2.5 (27.5)	-5.1 (22.8)	−12.0 (10.4)	−13.9 (7)
Average rainy days	12.9	11.9	12.2	12.5	11.7	10.2	6.1	5.3	7.0	9.0	9.9	12.0	120.7

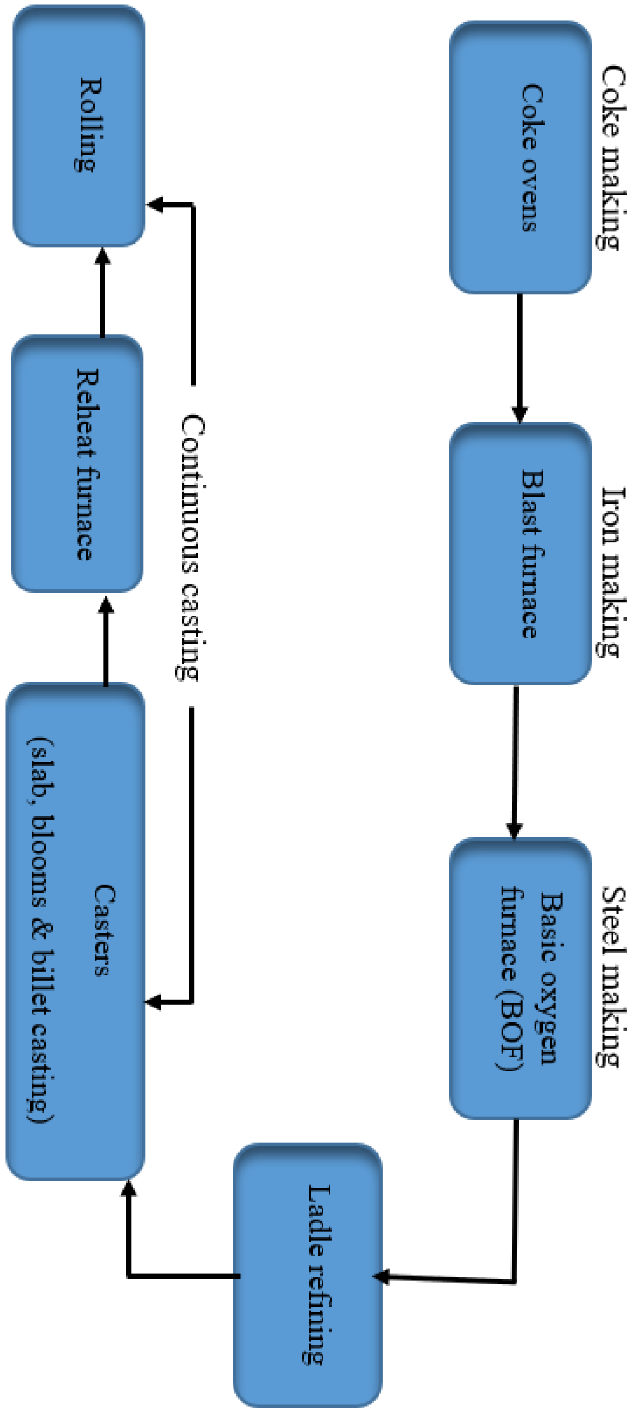


Figure 4.2. Iron and steel processing flow chart in Kardemir factories.

Below, a summarized list of the steps involved in steel production is given. For more clarity and a better understanding of their connection, referring to figure 4.2 is highly advised.

1. Agglomeration approaches
   1.1. Sintering
   1.2. Pelletizing
   1.3. Briquetting
2. Cokemaking
3. Ironmaking, which includes:
   3.1. Blast Furnace
   3.2. Direct Reduction
   3.3. Direct Ironmaking
4. Steelmaking, which in turn includes:
   4.1. Basic Oxygen Furnace (BOF) Steelmaking
   4.2. Electric Arc Furnace (EAF) Steelmaking
5. Ladle refining and casting
   5.1. Ladle Refining for BOF and EAF
   5.2. Casting
6. Rolling and completing
   6.1. Rolling and Forming
7. Finishing

4.2. DATA COLLECTION METHOD

The approach designed to address our objectives includes a questionnaire for the workers, observations, measurements, data collection and statistical analysis. Field considers are carried out to examine and degree the hot environment conditions of workers at their work environment by measuring factors in their encompassing environment. In addition, they are handed a questionnaire and asked to vote on their thermal sensation. Their feedback is used to assess the influence of heat stress on the workers performance and productivity. In order to have a comprehensive picture and fulfill the requirements for a thorough assessment of the working environment, data were collected for six parameters which are as follows:

1. Temperature of the air
2. Mean radiant temperature
3. Humidity
4. Air velocity
5. Workers' metabolic rate during their working process
6. Clothing factor

Other physiological parameters that were measured and included in the analysis are:

1. core temperature
2. heart rate

After all the measurements were collected, they were organized in the form of tidy data sheets ready for analysis by using Microsoft Excel software. Further statistical analysis were carried out using Statistical Package software (IBM SPSS Statistics 20.0). Descriptive statistics such as frequency, mean, standard deviation etc. were calculated in addition to inferential statistical tests such as correlation and regression analysis to decide the connections between the variables on interest.

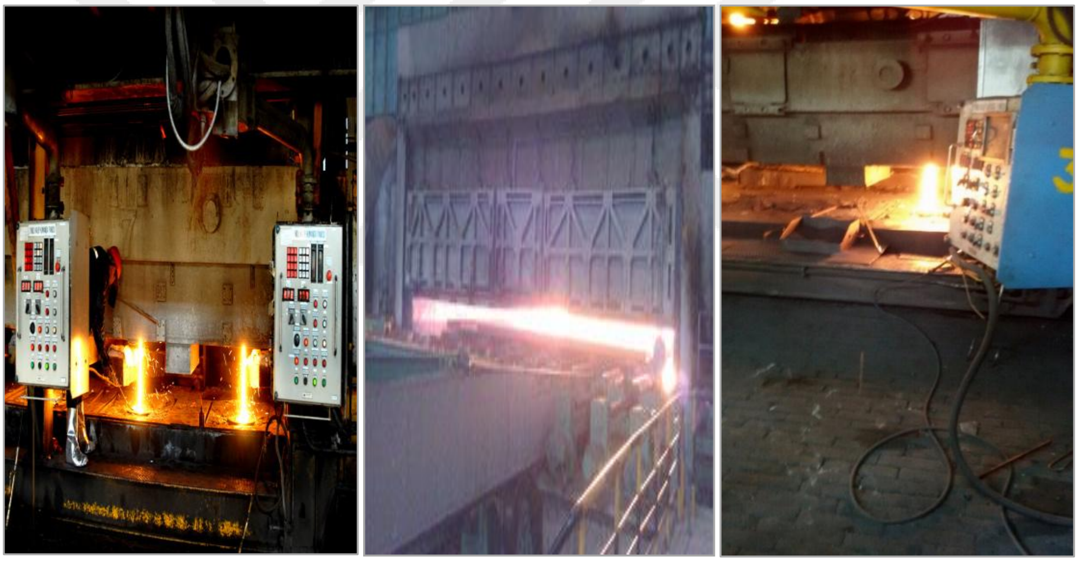
There were two strategies for measurements: the first one involving measurements and the survey was the location where the measurements were taken (figures 4.3-4.5) and the selection of the season. The three seasons, spring, summer and winter were selected because according to the local climatic conditions they represent extreme thermal conditions within the whole year, since they represent the coldest and hottest times year-round, particularly the months of April, July, and January. The second strategy was the selection of the time to carry out the survey on a particular day. The survey was carried out during the working hours on the day shift on two intervals, from 9 to 12 in the morning, from 1 to 4 afternoon. Iron and steel plant workers are exposed to excessive heat continuously for eight hours work shift, which cause discomfort and contributes to low productivity among them.

Location (1) Coke Plant – outdoor space

Location (2) Blast Furnace

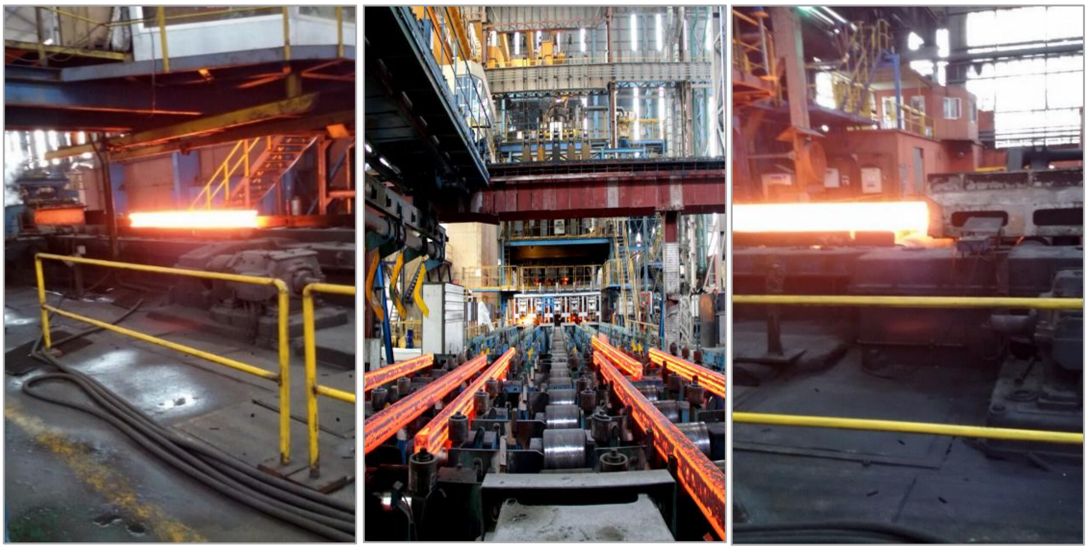
Figure 4.3. The chosen work environments for estimations and study.

Location (3) Basic Oxygen Furnace (B.O.F)



Location (4) Reheat Furnace

Figure 4.4. The chosen work environments for estimations and study.



Location (5) Hot rolling and Production of billets

Figure 4.5. The chosen work environments for estimations and study.

4.3. SAMPLING DESIGN

Sampling is an indispensable approach to modern scientific inquiry. Since it is impossible and impracticable to study the whole population for a certain number of variables, taking random samples and use their information to make inferences for the general population is the method of choice [123]. More formally, sampling is defined as the process of randomly choosing a statistically meaningful number of elements from a population of same nature, study their characteristics and the variables we are interested in, and extrapolate them to the general population by means of statistical tests to test their significance.

There are two main advantages of our sampling design: first, it was designed in a way to reduce the investigators biasness to the minimum possible, and second, it does not depend on the employees' availability for a certain work shift. The participants of this study were both experienced and healthy workers from Kardemir plant. Selection process was based on a number of criteria, the most important ones being their age, gender (all were males), disease's nature and stage if applying and the treatment they have been under history. There were also a number of exclusion criteria, such as presence of flu during the participation week or the one prior. Exclusion also applied for workers with severe diseases, such as diabetes, cardiovascular disease, hypertension, neurological problems and those under regular medication. All participants were wearing the standard attire of long-sleeved shirts, long trousers and safety shoes. In addition, all the participants were informed in advance about the nature and importance of the study, especially their responses and recommendation, for the future of the industry. Both the survey and measurements of our values of interest were finished at the same time in all five spots of the plant during the hot summer season from June to August 2016. The total sample involved 100 workers (20 per spot) who were constantly exposed to heat in different workstations. Their selection was primarily based on their working area, the type of work they were doing, and their health status and medication history.

4.4. DESIGN OF QUESTIONNAIRE SURVEY

The questionnaire was created after a profound and comprehensive survey of the accessible writing on heat exposure and occupational health. It was designed and administered with the intention to gather information on the type of thermal environment problems experienced by employees in their respective workplaces. Its focus was the evaluation of a number of variables in working environments that affected employees' productivity and performance while they were carrying out their duties. In order to formulate the questions so that they would be relevant to the problem at hand, karabuk University was utilized. It for the most part took between 20 to 30 minutes to fill within the foundation data, word related data and 15 closed-ended address related to warm working environment conditions, such as thermal sensations humidity, and air quality. There were too questions concerning the frame of work, sum of every day water admissions, rest periods, and activity level amid the working hours. There was moreover one open-ended question included within the survey almost advancements that the workers would like to have. The survey was conducted as it were once and all the questions were in Turkish, which is talked by all the employees at the plant. In expansion, there was too a brief meet to supply more clarifications almost the purpose of the study and the value of data given by each worker. They were energized to precise their conclusions openly. The night shift workers were also to be given questionnaires for filling. Night shift workers filled their questionnaires in the morning while the day shift workers filled their questionnaires during their free time.

The work shift of the members ran from 09:00 am to 17:00. All the concerned people were work force and they were wearing light-weight blue cotton uniforms, helmet, and protection footwear all through summer season. For more viable security, blast furnace laborers were wearing aluminum clothing for PPEs and they were standing at separations of 1.5-2.0 meters absent from the furnace. Amid winter, additional layers of clothing was provided for insulation in cold climate conditions for all the staff working exterior (coke plant). The guidelines of ISO 9920 [93], were utilized to assess the normal clothing value which was adjusted to 0.8 clo.

4.5. MEASUREMENT OF ENVIRONMENTAL VARIABLES

All the instruments used to measure out variables of interest were placed in the working environment of interest in as real a setting as possible without distracting the working process of the employees. In addition, enough time was given for them to stabilize and be correctly calibrated. The readings were repeated to obtain statistically significant results. Measurements were taken at 9:00 a.m., 12:00 a.m. (late morning), and 16:00 p.m. once a month through the three months consider. Measuring areas were chosen as near as conceivable to the worker's action location without interferometer with their work. Natural parameters of Ta, Tg, MRT, RH, Va, and WBGT were measured at the desired places with a handheld WBGT screen (Extech HT30), and a multi-functional measuring instrument (Testo 435-4) fig.4.6 which comprises of an instrument pack with classical wired probes as well as wireless probes which can be worked from remove as distant as 20 meters backed by a 1.1 meters tall tripod was utilized.

Figure 4.6. WBGT monitor (Extech HT30) and instrument kit (Testo435-4)

4.6. MEASUREMENT OF PHYSIOLOGICAL PARAMETERS

4.6.1. Heart Rate

Normally, a person's heart rate (HR) is measured in beats per minute (bpm) and it varies between 60 and 100 bpm. In working condition, elevated heart rate serves as a guide to a person's health state, and it can be caused by a number of factors such as physical activity and physiological response to heat stress. Measuring physiological parameters (the center body temperature and beat rate) were performed whereas the workers were in standing position in rest room found 30 m away from the work environment in each unit. Apart from the laborers of coke stove found outside and blast furnace found inside, their body temperature and heart rate were measured within the course of work in standing position.

4.6.2. Body Core Temperature

Normally, deep tissue temperature (also known as core body temperature) of a person is maintained within a very strict range of $0.5C^0$ since big variations could be fatal. Since actual measurement of core body temperature is very difficult in practice, a number of methods have been designed to estimate it as accurately as possible. Among the most common methods are the measurement of sublingual, tympanic, rectal, esophageal, and gastrointestinal tract temperatures. The core temperature varies between 36°C to 38°C, and any change beyond these can turn out to be fatal or with severe consequences for the health and psychological state of a person.

Measurements of heart rate and center temperature were performed half an hour some time recently work, 2 hours after beginning work, and one hour after lunch break. Estimations of blood pressure and beat rate were performed with Omron M2 screen (figure 4.8). This instrument measures blood weight (Systolic & Diastolic) and beat rate at the same time. For estimation of core body temperature, Braun ear ThermoScan (fig.4.8) was utilized to assess core body temperature by measuring the temperature within the ear canal by holding up for a least of two minutes some time recently taking readings. The instruments were calibrated some time recently and after estimations. Information were manually recorded, at that point the mean values were calculated. Metabolic rates (M) was calculated from the worker's heart rate, age, and body weight by utilizing the strategies given in ISO 8996 [124].

Figure 4.7. Omron M2 monitor and Braun ear ThermoScan.

$T_{re,o}$ and $T_{re,t}$ demonstrate the rectal temperatures at rest and amid work, HR_0 and HR_t appear the heart rate at rest and work individually. HR_0 , and $T_{re,o}$ were gotten within the standing position 30 minutes some time recently work within the resting room. HR_t and $T_{re,t}$ were gotten 2 hours after beginning the work.. In total during working hours monitoring values of heart rate, core temperature, WBGT and the environmental parameters, were recorded. PSI and HSI Indices were calculated based on equations (2.18-2.23).

4.7. AIR QUALITY

The production of iron and steel includes the utilization and age of an assortment of inhalable agents including, however not restricted to, gases, vapours, dusts, fumes, smokes and aerosols. These agents comprise a variety of toxicological hazards including irritants, chemical asphyxiants, fibrogens, allergens, carcinogens and systemic toxicants. As mentioned previously in the context of air pollution and the race to find solution to them, integrated steel plants are one of the main sources of two dangerous gases, namely sulphur oxides ($\boldsymbol{SO_x}$) and Nitrogen oxides ($\boldsymbol{NO_x}$). In arrange to look at discuss emissions within the steel plant range and to survey the impacts of poisons on workers' wellbeing interior the existing work environment, concentrations of discuss poisons were continuously measured and collected in

Kardemir plant within the course of 12 months in 2016 by Turkish discuss quality stations through a network of monitoring stations over the nation [107, 125]. The observing network includes day by day estimations of environmental parameters and air pollutants in a number of areas within the nation. Table 2 the World Wellbeing Organization (WHO) emission limits for the concentration values of PM_{10}, NO_2, SO_2, and NO_x [126].

4.8. PRODUCTIVITY IMPACT

In any industry in general, and steel industry in particular, workers' performance is the most important dependent variable. The decline in productivity (performance loss) was estimated based on two previous researchers' methods. Each method has its own strengths and limitations, and requires somewhat different data for its implementation. The primary could be a measure of the relationship between employees' capacity, extraordinary WBGT level and work force as a chart based on the ISO 7243 for acclimatized people, as said in chapter two. These theoretical comes about were at that point compared with the overview comes about. The second strategy is based on the theory that productivity can be predicted as a work of the anticipated mean vote (PMV) index within the construction industry by implies of a polynomial regression investigation method. PMV was chosen due to its capability to coordinate the impacts of thermal environment factors, the nature of the work task being performed, and the clothing gatherings worn by workers, and give a single value as a thermal list, then the developed PMV-productivity model represents the productivity percentage for heavy workload.

4.9. DATA ANALYSIS

The collected information from the survey and physical estimations were analyzed utilizing Measurable Package for Social Science (SPSS) program version 20 and Microsoft Excel. The information was too analyzed utilizing descriptive statistics, where the means and standard deviations of the results were calculated independently for laborers in each working environment. Contrasts within the result factors between groups were tested utilizing the Kruskal-Wallis and Chi-square tests. Pearson relationship examination was utilized to decide the correlation between physiological parameters and heat stress indices, where the significance level for all examination was set to be 0.01 at 95% certainty. Cronbach's alpha examination was utilized to represent the inside consistency and reliability of all the constituents of the survey. In the present work some of the most common and convenient statistical tools to quantify our results are:

1. **A correlation** is valuable when we need to see the relationship between two (or more) ordinarily conveyed interval factors.
2. **An independent samples t-test** is utilized when we need to compare the means of an ordinarily dispersed interval dependent variable for two independent groups.
3. **Analysis of variance (ANOVA):** When results of laboratories or strategies are compared with more than one figure can be of impact and must be recognized from irregular impacts, at that point ANOVA could be a effective measurable device to be utilized.
4. **A chi-square test** is utilized when we need to see on the off chance that there's a relationship between two categorical factors. In SPSS, the chi-sq. choice is utilized on the statistics subcommand of the crosstabs command to get the test statistic and its related p-value.
5. **The Kruskal Wallis test** is the non-parametric form of ANOVA and a generalized frame of the Mann-Whitney test since it is utilized to compare the contrasts between two or more groups.

CHAPTER 5

RESULTS AND DISCUSSION

5.1. STUDY SAMPLE

The larger part extended from 33 to 43 years old. The mean work experience was 9.79±5.76 years, and there was no critical relationship between laborers experience and their working environments ($p_= 0.345$). At long last, 70% of the laborers were non-smokers. The internal consistency reliability of the survey anticipated by way of Cronbach Alpha coefficient (α) was 0.681, which is considered an worthy value, after expelling the factors related to the laborers' position amid work (standing, strolling, or both). A series of proposals were inferred based on the input of these surveys. Table 5.1 summarizes the participants' characteristics. Figure 5.1 outlines the rate of steel workers wearing an individual defensive gear (PPE) whereas working. More than half of workers detailed they are walking, and standing as it were amid a work shift, and 40% said they are walking, standing, and sitting as appeared in figure.5.2.

Table 5.1. Laborers characteristics. (No. of workers$_=$ 100 male).

Variables	***Min.***	***Max.***	***Mean***	***S.D***
Age (years)	*25.0*	*51.0*	*37.55*	*5.855*
Height (cm)	*168.0*	*188.0*	*178.9*	*5.68*
Body mass (kg)	*75.0*	*88.0*	*80.30*	*4.41*
Work experience (years)	*1.0*	*21.0*	*9.791*	*5.767*
Daily water intake (liter)	*0.33*	*2.0*	*0.67*	*0.64*

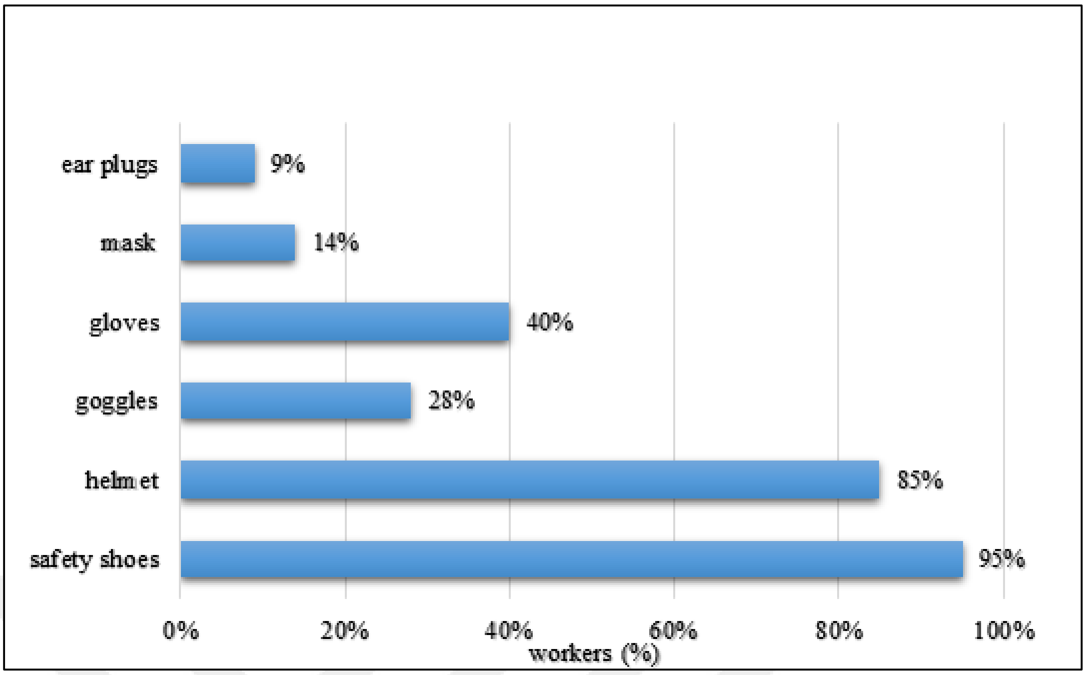


Figure 5.1.Workers wearing P.P.E from survey

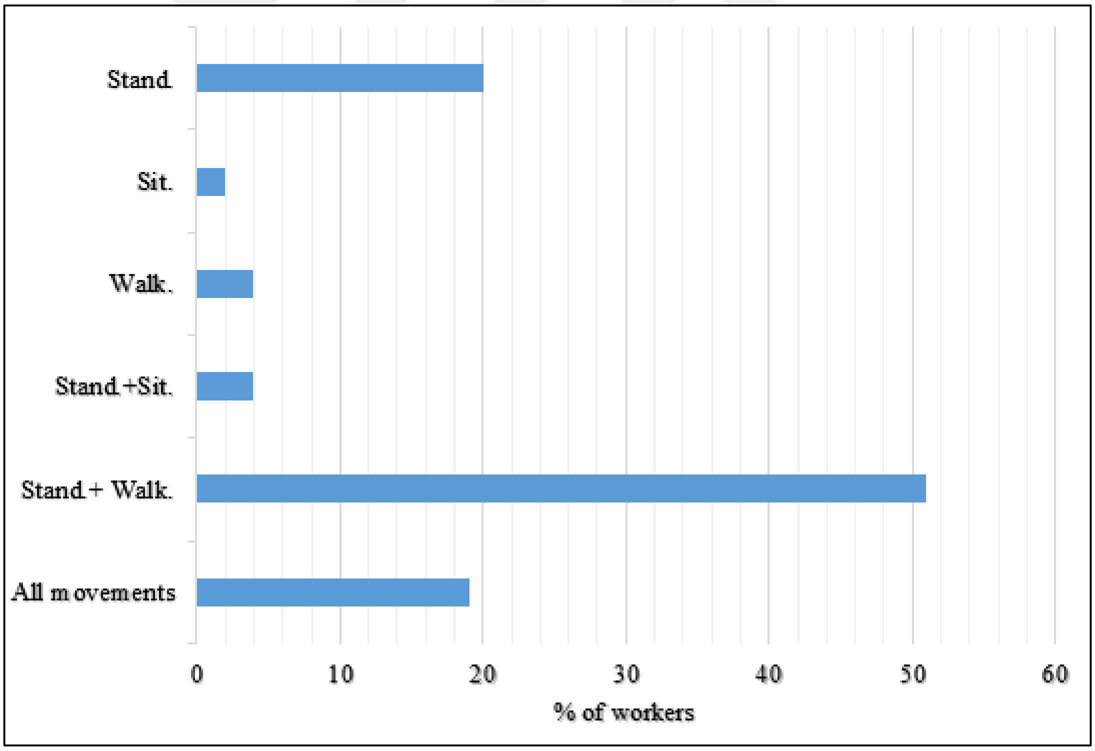


Figure 5.2.Worker position and movement.

5.2. ENVIRONMENTAL CHANGES MEASUREMENTS

The average ambient temperatures at the zone of the steel plant during: April (Ta=24℃). July, August (Ta=38℃). December, January (Ta= - 4℃), while the measured environmental parameters in each workstation are shown in table 5.1:

Table 5.2. Results of environmental parameters measurements in each workstation.

Coke plant			
Environmental variable	**April**	**July, August**	**December, January**
T_a℃	39	47	27.4
T_w℃	25.21	28.38	13.17
T_g℃	47	49.5	44
RH	33	25	16
$WBGT$ ℃	30.94	34.46	20.76
Blast furnace			
T_a℃	38	40.9	23
T_w℃	25	25.74	9.72
T_g℃	42	44	26
RH	35	30	12
$WBGT$ ℃	30.1	31.21	15
B.O.F			
T_a℃	34.5	39.7	17
T_w℃	22.76	24.3	7.58
T_g℃	36	42	27
RH	35	28	22
$WBGT$℃	26.69	29.61	13.5
Reheat furnace			
T_a℃	38	42	19
T_w℃	26.27	26.83	9.16
T_g℃	41.2	45	28

Table 5.3. (continued)

RH	40	31	23.5
$WBGT$℃	30.7	32.2	14.8
Hot rolling (rails profiles)			
T_a℃	32	39	16
T_w℃	21.61	24.38	8.62
T_g℃	33.9	41.7	22
RH	40	30	35
$WBGT$℃	25.3	29.57	12.63

5.3. HEAT STRESS PROFILES

Comes about from the study appeared that the larger part of workers complained of thermal distress in their work environments, where the surrounding temperatures extended from 34 to 40.9 ℃ all through hot summer days. 44% of the participants specified that they were feeling very hot, taken after by 52% who were feeling hot, and at last 4% who were feeling warm. Heat rashes are the foremost common issue within the chosen work environments, which in most cases vanish when the influenced worker returns to the cool resting room. There was no critical distinction of thermal discomfort level experienced by representatives working totally different work environments ($p_= 0.647$). Figure 5.3 appears the distribution of survey's participants' thermal sensation for all workstations.

Guideline comes about from the anticipated heat stress and strain indices appeared that the mean values of WBGT, PSI and HSI over the steel plant were 30.89±1.1℃, 3.15 ±0.64 and 118.5±18.61%, individually amid the month of August. High levels of heat stress were watched near to furnaces and hot rolling region. The least WBGT, HSI and PSI were found within the open air coke stoves zone with values of 29.87±1.26℃, 92.13% ±2.82, and 2.22±0.15 separately (Table 5.3), where the level of heat strain experienced by the workers was not considered over the top for acclimatized workers. Based on the full expected scores of PSI, the heat strain extended from none/little to low in all units. The results affirmed that the cruel WBGT values within the five working environments surpass the limit constrain value

(TVLs) of 28℃ WBGT suggested by American Conference of Governmental Industrial Hygienists (ACGIH) in summer time [115]. Agreeing to the ACGIH screening criteria (WBGT in °C) for 8 hours work five days a week with customary breaks for a work including heavy work (Table 5.4), one-hour shift ought to be part into 30 minutes of work and 30 minutes resting in coke stoves and rolling mills regions, and 25% work and 75% rest for laborers in furnaces zones. Coke oven workers were monitored in the summer months, where climatic conditions were high enough to expect an elevation in WBGT beyond that due to solar radiation, it was 29.87±1.26°C. In contrast, indoor workers were monitored in the summer months, where climatic heat stress was high and acceding the recommended limits (WBGT ≥ 30˚C) [127].

The anticipated values of HSI at working environment air speed of less than 1m⁄s were compared with the measured WBGT on the same conditions and were not consistent with each other. This can be due to the low exactness of HSI in situations of such low wind speed, meaning that this index isn't suitable for all working environment thermal conditions. Agreeing to the comes about of Hajizadeh et al. [128], values of HSI index are as well overstated; when the wind stream rate is rise to or near to zero, the estimations are higher than the real values. Subsequently, the HSI list can be utilized under certain circumstances as a supplement list of WBGT. Their study appeared that the WBGT and HSI had the highest relationship with other physiological parameters among the other heat stress indices amid heavy work exercises in hot and dry climates, which is in line with our results. The ideal index was chosen fundamentally based on the relationship coefficient between the different indices with each other as well as with physiological parameters within the exposed samples.

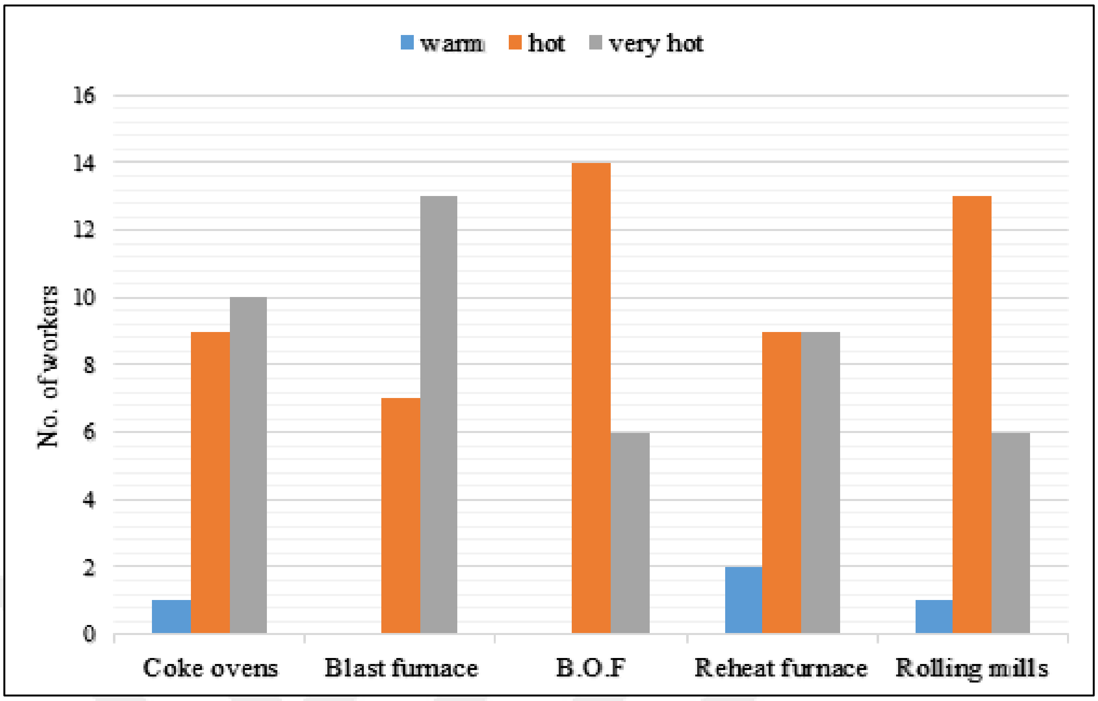


Figure 5.3. Thermal sensation votes from survey.

In any case, in a steel industry, the indices of HSI, WBGT, ET and CET did not have a significant relationship with deep and oral temperatures [129]. Further, Golbabaei et al. [130], inspected the relations between the thermal stress indices to create an ideal index based on physiological parameters in petrochemical industry. Agreeing to them, the finest index connecting with heart rate was WBGT, so it was chosen as the ideal index for hot and humid surroundings.

Table 5.4.Heat stress indices, environmental and physiological measurements, $(Mean \mp S.D)$.

Parameter	***Coke ovens***	***B.F***	***B.O.F***	***Reheat furnace***	***Rolling mills***
T_a (℃)	*37.5 ± 3.13*	*39.6±2.62*	*38.1±2.41*	*38.0±1.32*	*37.4±1.81*
T_g (℃)	*42.6±4.11*	*46.4±4.31*	*44.1±3.33*	*45.0±4.70*	*423±2.42*
T_{mrt} (℃)	*58.1±1.23*	*62.4±1.0*	*57.6±1.62*	*57.1±1.3*	*50.5±1.6*
RH (%)	*32±5.15*	*34±3.73*	*34±3.90*	*41±2.65*	*41±3.48*
V_a (m/s)	*2.31±0.46*	*1.61±0.32*	*1.41±0.7*	*0.9±0.34*	*0.8±0.44*
HR (bpm)	*92.3±4.32*	*104.2±7.7*	*98.2±10.4*	*102.7±81*	*102.1±6.6*
T_{core} (℃)	*37.33±0.37*	*37.94±0.12*	*37.70±0.35*	*37.45±0.41*	*37.34±0.45*

Table 5.5. (continued)

WBGT (℃)	***29.87±1.26***	***31.32±0.8***	***31.25±0.75***	***31.34±0.74***	***30.68±1.14***
HSI (%)	*92.12±2.81*	*118.5±9.44*	*109.7±4.8*	*134.2 ±19.41*	*137.82±18.46*
PSI	*2.23±0.16*	*4.03±0.31*	*3.31±0.17*	*3.14±0.32*	*3.11±0.41*

Table 5.6. ACGIH Screening Criteria for Heat Stress Presentation (WBGT values in °C) for 8 hour work day five days per week with routine breaks.

Work Demand	***Percentage of work in a cycle of work and recovery in an hour***			
	75 – 100%	***50 – 75%***	***25 – 50%***	***0 – 25%***
Light	*31.1*	*31.1*	*32.1*	*32.6*
Moderate	*28.1*	*29.1*	*30.1*	*31.6*
Heavy	-	*27.6*	*29.6*	*30.6*
Very Heavy	-	-	*28.1*	*30.1*

5.4. PHYSIOLOGICAL CHANGES MEASUREMENTS

The physiological changes of beat rate and body center temperature were measured, and the cruel values of the complete sample were 99.93±8.39 beats per minute and 37.56±0.42℃, individually. Pearson relationship appeared a strong positive relationship (r =.648) between WBGT and PSI index, as well as between WBGT and core body temperature (r =.725) as appeared in Table 5.5. Each participant had a mean value for their HR, and center temperature over their shift. In this manner, gather information reports an normal mean value for these factors. The core temperature and heart rate of a agent worker all through the shift is displayed in Table 5.3. From the heart rate information, and center temperature were the normal values extended between 92 and 104 beats per minute (bpm),and *37.32* to *37.95* ˚C. The maximum core temperature recorded was *37.95±0.11* ˚C.

among blast furnace workers and *37.71±0.34* ˚C among basic oxygen furnace workers. The Australian Institute of Occupational Hygienists (AIOH) [131], recommends that an individual's exposure to heat stress be discontinued if core body temperature is ≥ *38.5* ˚C (for medically selected and acclimatised personnel) or ≥

38.0 ˚C (for un-selected and un- acclimatised workers). Similar recommendations are provided by ISO 2004b. According to the heart rate data, it would appear that B.F, Reheat.F, and rolling crews have the highest values, which may explain why they showed similar core body temperature fluctuations. OSHA Technical Manual [132], the another period of work shift ought to be abbreviated by one third and the rest period ought to be preserved. Most respondents thought that the rest periods and lunch break are brief and must be expanded amid summer season. When it comes to laborers movements and position amid work shift, more than half of them detailed walking and standing, and 40% said they were walking, standing, and sitting, depending on wants of the process. The average water intake reported amid work shift for each laborer was 0.67±0.64 liters, which isn't sufficient to supplant the sweating rate and dodge health dangers. Body water loss was measured by weighing the laborer on a scale at the begin and end of work shift. In spite of the fact that the worker's weight loss did not surpass 1.5% of add up to body weight, specialists were energized to extend liquid intake amid work in arrange to avoid dehydration.

Table 5.7. Outline of correlation results.

Variables		T_{core} (℃)	**HR** (bpm)	**WBGT** (℃)	**HSI** (%)	**PSI**
T_{core} (℃)	*r*	1.0	.6050**	.7210**	.3340	.7250**
	P-value		.0000	.0000	.0710	.0000
HR (bpm)	*r*	.6050**	1.0	.5170**	.6780**	.6480**
	P- value	.0000		.0030	.0000	.0000
WBGT (℃)	*r*	.7210**	.5170**	1.0	.4650**	.6230**
	P- value	.0000	.0030		.0100	.0000
HSI (%)	*r*	.3340	.6780**	.4650**	1.0	.5350**
	P-value	.0710	.0000	.0100		.0020
PSI	*r*	.7250**	.6480**	.6230**	.5350**	1.0
	P-value	.0000	.0000	.0000	.0020	

****.** Correlation is significant at the 0.010 level (2-tailed).

5.5. HEAT AND AIR POLLUTION-RELATED HEALTH IMPACTS

Approximately 85% of people complained of heat presentation and contamination since of dust and gas emanations, counting particulate matter, sulfur oxides, and carbon monoxides, which start for the most part from air outflows in blast and basic oxygen furnaces. According to Table 5.6, the normal yearly concentrations of PM_{10} was greater than WHO limits. SO_2 and NO_x concentrations surpassed by around 25 %. Hence ventilation, air cooling, fans, protecting, and separator are critical controls utilized to diminish warm push and discuss contamination in hot work environments. Around 30% of laborers complained of wellbeing and social issues coming about from word related warm stretch and discuss defilement. Their complains included shortcoming, intemperate sweating, migraine, a expansive rate of hearing misfortune, need of ventilation and, as well exhausted to spend quality time with the family after finishing work. As per 2016 every day information recorded from the Occupational Wellbeing and Safety Division in Kardemir steel plant, there were no wounds and accidents. Whereas no workers within the display think about had a medically reportable case or serious indications of heat illness which caused them to stop work.

It shows up most likely that it is the air contamination status of the plant units, combined with the expanded climatic heat stress in summer, which is contributing to the heat illness side effects experienced by workers.

Table 5.8. Comparison of (WHO) emanation limits of $\mathbf{PM_{10}}$, $\mathbf{NO_2}$, $\mathbf{SO_2}$, and $\mathbf{NO_x}$, with the assessed values in Kardemir steel plant.

Pollutant	***Annual average concentration*** ($\mu g/m^3$)	
	Limit value (WHO)	**Recorded value**
PM_{10}	20.0	86.0
NO_2	40.0	50.0
SO_2	20.0 (daily average)	17.0 (daily average)
NO_x	25.0	24.0

5.6. PRODUCTIVITY

Nearly two-thirds of the workers expressed their exercises were excessive amid the primary half of work shift some time recently lunch break and they thought their efficiency loss was around 30% within the remaining hours of the move. 17% claimed their movement levels were high amid all hours of work and 19% detailed their performance expanded 2 hours after beginning work (figure 5.4). The Kruskal-Wallis examination confirmed that there were measurably significant contrasts in laborers by and large performance levels some time recently (x^2 (2)=8.100, p = .017), and after lunch breaks (x^2 (2)=12.316, p = .002) among all units. In differentiate, ANOVA investigation demonstrated that there was no critical relationship between workers experience and their movement levels some time recently (p=0.345) and after lunch (p=0.711). The Percent productivity loss extended from 61 to 76%. Agreeing to the figure 5, there was a critical distinction in productivity level of laborers assessed from the study and the ones gotten from the WBGT vs. productivity loss bend (Figure 2). The comes about may change due to studies performed completely different sorts of industries and nations. Additionally, the ISO standard utilized for plotting the WBGT vs. productivity loss curve expect that workers take rest within the same environment when they work, but laborers in Kardemir plant tend to require rest in cooler rest rooms. In differentiate, performance loss values from the study comes about in figure 3 are in line with the calculated values from condition (7) for PMV-productivity demonstrate, extending from 20 to 30 % productivity losses for a heavy workload.

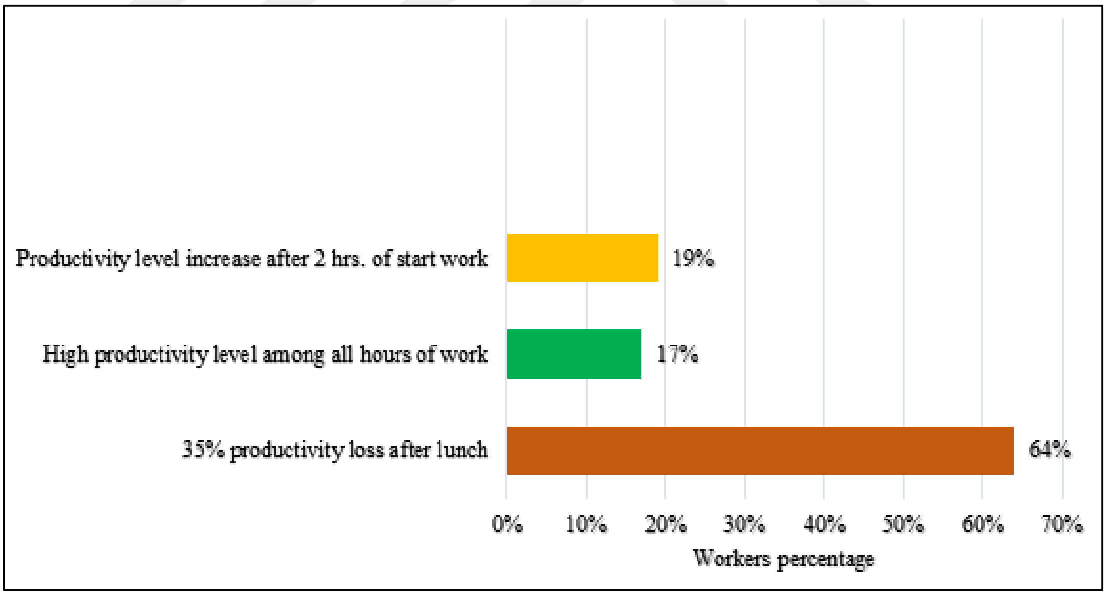


Figure 5.4.Workers’ productivity percentage from the survey.

5.7. DISCUSSION

The display study appears that furnace laborers are uncovered to more heat stress than others (WBGT= 31.25, 31.32, and 31.34℃) which is comprise with the study of Ghanbary et al. [133]. Mediation can be worn out arrange to diminish radiant heat around the furnaces by employing a heat absorbing framework within the furnace body and introducing intelligent barriers. Omid Giahi et al. [134], affirmed that heat control at the heat source can be considered as a to begin with arrangement for lessening radiant heat of blast furnaces by introducing intelligent aluminum boundary within the primary workstation of steel industry. Their comes about appeared that WBGT lists diminished by 3.9°C.

The relationship between heat stress indices and physiological parameters of heart rate and center temperature demonstrated a noteworthy relationship between them. HSI appeared a better relationship than the other lists with heart rate. In any case, WBGT and PSI indices shown a noteworthy relationship with center body temperature. Besides, a moderately powerless relationship was watched between the HSI and center body temperature.

The findings of a study by Habibi et al. [135], confirmed our results and showed that the WBGT had a direct significant correlation with the physiological variables of heart rate, oral temperature, and PSI.

The results appeared critical relationship between PSI, WBGT, and HSI. Hence, PSI index appeared more relationship than others. In Dehghan et al. study [136], the profound body temperature parameter had a much higher relationship with a HSI than the WBGT file. In expansion, PSI was more strongly related with the HSI than the WBGT index; they are all reliable with the comes about of our study.

On the other hand, Heidari et, al. [137], considered workers who were encountering high heat stress and found the most elevated relationship between aural temperature and WBGT, an perception not in understanding with the comes about of the display study.

To approve the indices, the considered index ought to have a solid significant relationship with physiological parameters. In this study, the ideal index was chosen by examining the relationship coefficient between the different records with each other as well as with physiological parameters. Be that as it may, this study appeared that the WBGT and PSI lists had the most noteworthy relationship with physiological parameters as compared to the HSI list.

Concurring to figure 5, there was a critical distinction in efficiency levels of workers evaluated from the survey and the ones gotten from the WBGT vs. productivity loss curve (Figure 5.4). The results may shift for considers drained diverse sorts of industries and nations. Besides, the ISO standard utilized for plotting the WBGT vs. productivity loss bend assumes that workers take rest within the same environment where they work, but in reality laborers in Kardemir plant tend to require rest in a cooler rest room. In differentiate, values of performance loss from the overview comes about (Figure 3) are in line with the calculated values from equation (7) for PMV-productivity demonstrate, extending from 20 to 30 % efficiency loss amid heavy workload. In this way, the workers' efficiency loss evaluated in this study isn't a precise esteem, but an estimation. In a study conducted by Langkulsen et al.[138], the affect of climate alter on occupational wellbeing and productivity in Thailand was evaluated. They found the run of production misfortune to be from 10 to 66.7%, which is altogether distinctive from that of the present study likely due to distinctive levels of heat presentation, socio-economic contrasts, as well as distinctive dietary status and culture.

Agreeing to the outcomes of air pollutants in Kardemir plant, $\boldsymbol{PM_{10}}$ was 4 times more prominent than WHO limits in a year. These comes about affirm the results found for $\boldsymbol{PM_{10}}$ concentration exceeding the limits set by WHO in the districts within the locale around Kardemir [139]. The major reason for this condition is that the plant is encompassed by mountains and slopes and the wind speed isn't high sufficient to transport the contamination absent from the plant climate. Subsequently, utilizing respiratory protective devices to diminish or dispose of dangerous exposures to $\boldsymbol{PM_{10}}$ is an urgent measure.

CHAPTER 6

CONCLUSION AND RECOMMENDATIONS

6.1. CONCLUSION

The results from this study uncovered that thermal working conditions and discuss contamination have an impressive affect on workers' wellbeing and execution. These results indicates that the heat exposure and air pollution have the strongest effect on the health and performance level of employees, while noise are not considered important by workers. The type of personal protective equipment provided to mitigate against a radiant heat and air pollution for the protection of workers from occupational hazards should be improved or changed by good quality equipment.

The results illustrate that WBGT and PSI are the first pertinent indices for evaluation of heat stress inside the Kardemir steel plant. It is beneficial to note that the show study was conducted in hot and dry summer season, amid which a significant impact on the cardiovascular reaction, reactivity, and subjective weakness indications of workers merits concern. Findings in this study provide information to the management of the steel plant to prioritize potential strategies prevent workers from heat exposure and productivity loss.

In this manner, to improve the productivity of the laborers, wellbeing and safety ought to be considered as a matter of critical consideration within the plant, and laborers ought to be beneath consistent medical supervision. In expansion, there's a clear require for future investigate to conduct physiological observing of both center body temperature and hydration status of steel plant workers to decide in the event that the heat strain experienced surpasses the suggested limits.

6.2. RECOMMENDATIONS

This study draws baseline information on the effect of working environment on workers' health and performance. Therefore the following recommendations are proposed:

1. Provision of proper ventilation is a safety concern in steel plant workstations, such as areas of furnaces. Fans installed in the roofs and walls can supply fresh cooler air from outside and stop hot air gathering.
2. Strategies ought to incorporate viable instruction of the workforce, normal checking of hydration status, and arrangement of suitable liquids. Laborers ought to be well educated of the circumstances in their work environment that uncover them to heat stress and how dehydration can contrarily influence their wellbeing and performance.
3. Educational techniques ought to point to prepare laborers with the capacity to distinguish work situations and circumstances in which they will be exposed to heat stress. This will enable workers to superior evaluate when they ought to pace their work escalated to endure the work environment.

At long last, workers have to be well educated of the indications of heat sickness and be able to distinguish them by and by and in their colleagues. Fitting measures to lighten these indications ought to too be made known and encouraged. Moreover, there is a need for researchers to determine which factors can buffer the negative effects that workplace hazards can have on employee health and performance and can be compared with the findings of this study.

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APPENDIX A.

HEAT STRESS QUESTIONNAIRE

Questionnaire

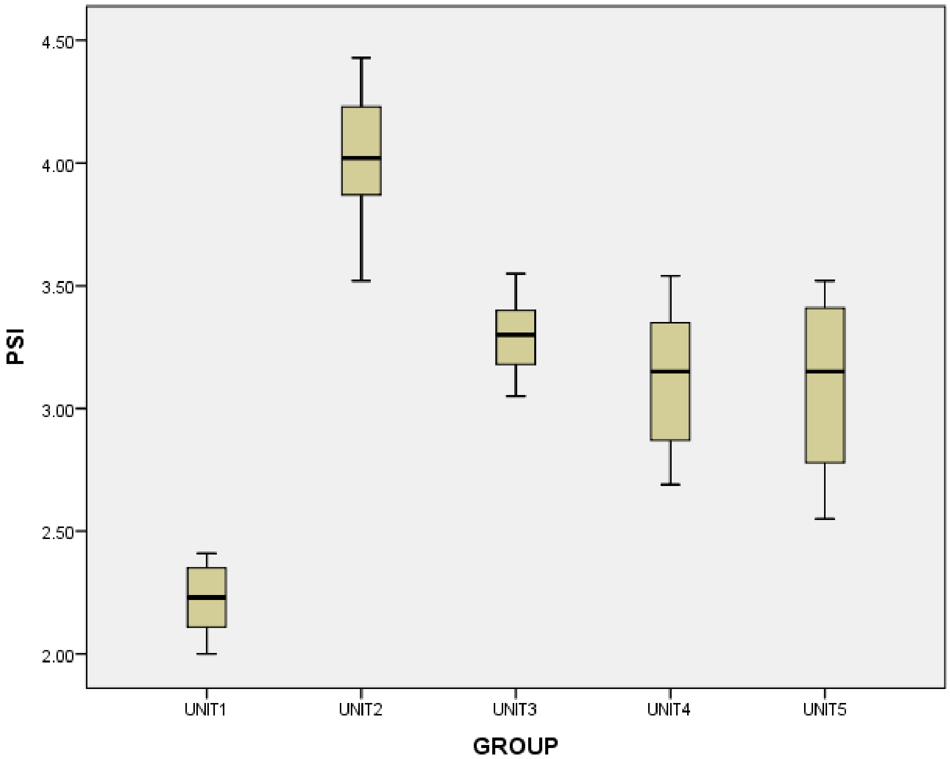
Factory code:		Work unit name:	Date:
Age:	Working hours:	Work start at: a.m. & finish at: p.m. Working experience: years	
1	Type of work. 1- sitting ( ) 2- standing ( ) 3 - walking ( )		
2	Number of resting hours. ( ) hr.		
3	Air temperature – Does the air feel - warm ( ) - hot ( ) - very hot ( )		
4	Radiant heat – What is the heat source in the workplace?		
5	Level of humidity - normal ( ) - dry ( ) - high humidity ( )		
6	Air freshness - normal ( ) - dirty ( ) - insufficient air flow ( ) - smoking gases ( )		
7	In general, how would you describe the thermal conditions of your workplace? - Very hot ( ) - Hot ( ) - Warm ( ) - Slightly warm ( ) - Neutral ( )		
8	What type of clothes you wear? - Lightweight work uniform ( ) - Protective clothing ( )		
9	What is hottest time of the working day in your opinion? - In the start of shiftwork ( ) - In the middle of shiftwork ( ) - Before the end of shiftwork ( )		
10	Do you sweat during the work? Yes ( ), no ( ) If yes, your sweating rate is - light ( ), high ( )		
11	What is the amount of water you drink during the shiftwork? (1/3 L) – (2/3 L) – (1 L)- (>1L)		
12	Is the rest hours enough to refresh your efficiency? Yes ( ) - not enough ( )		
13	Do you think that your productivity is at high level during : - Start of work ( ) - After 2 hours ( ) - Other time ( )		
	Please list any additional information’s that you think it’s important to increase thermal conditions.		

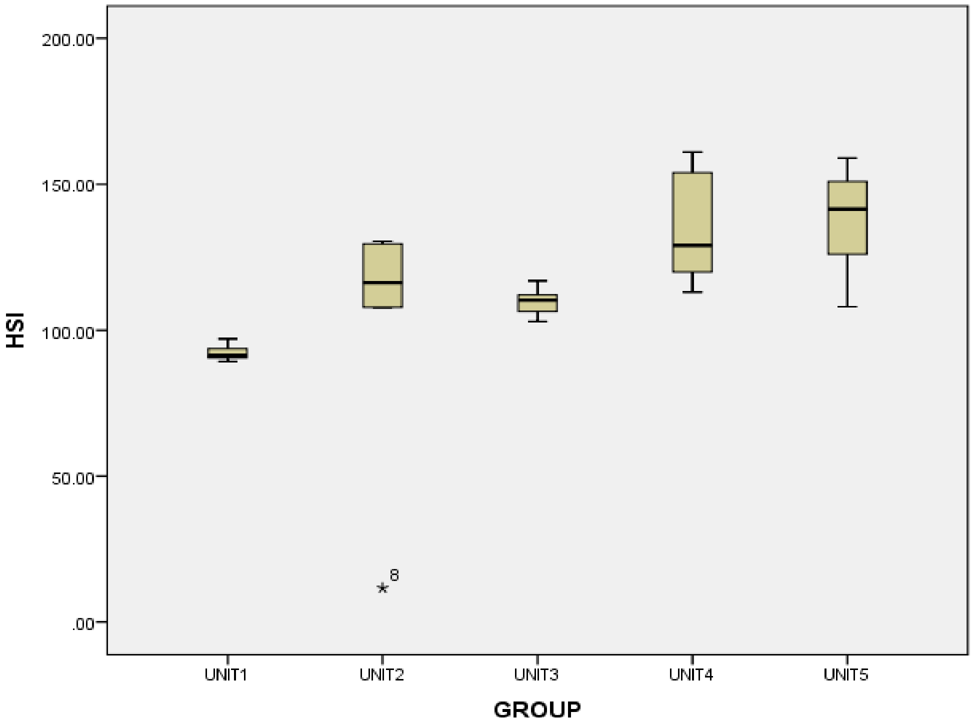
APPENDIX B.

DESCRIPTIVE STATISTICS AND CORRELATIONS

Descriptive Statistics

	N	Minimum	Maximum	Mean	Std. Deviation
T_{core}	30	36.86	38.08	37.5577	.41625
HR	30	87.00	114.00	99.9300	8.39323
WBGT	30	28.50	32.30	30.8903	1.06349
HSI	30	11.70	161.00	115.2267	28.52593
PSI	30	2.00	4.43	3.1503	.63823
Valid N (list wise)	30				

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UNIT4
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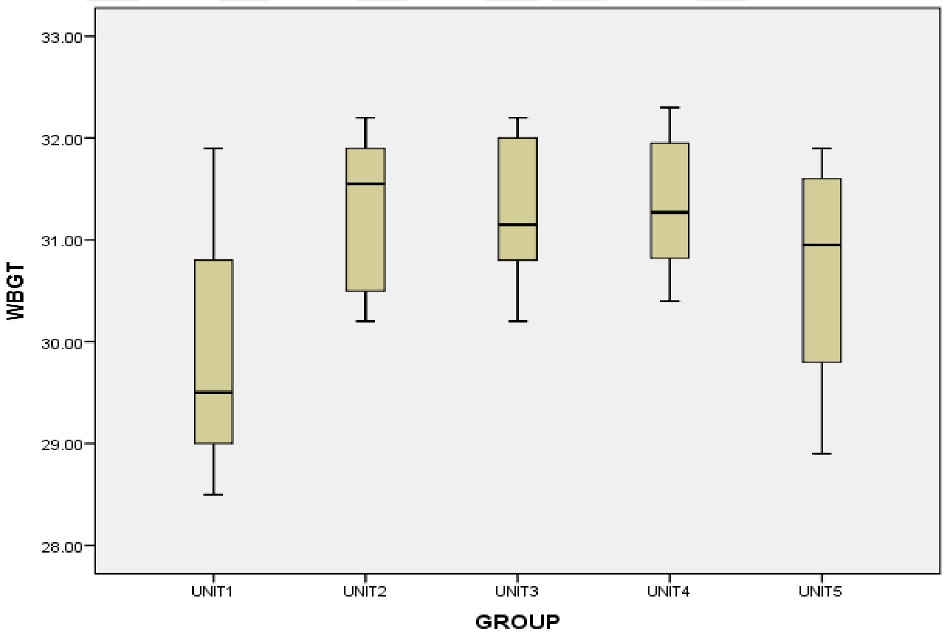
GROUP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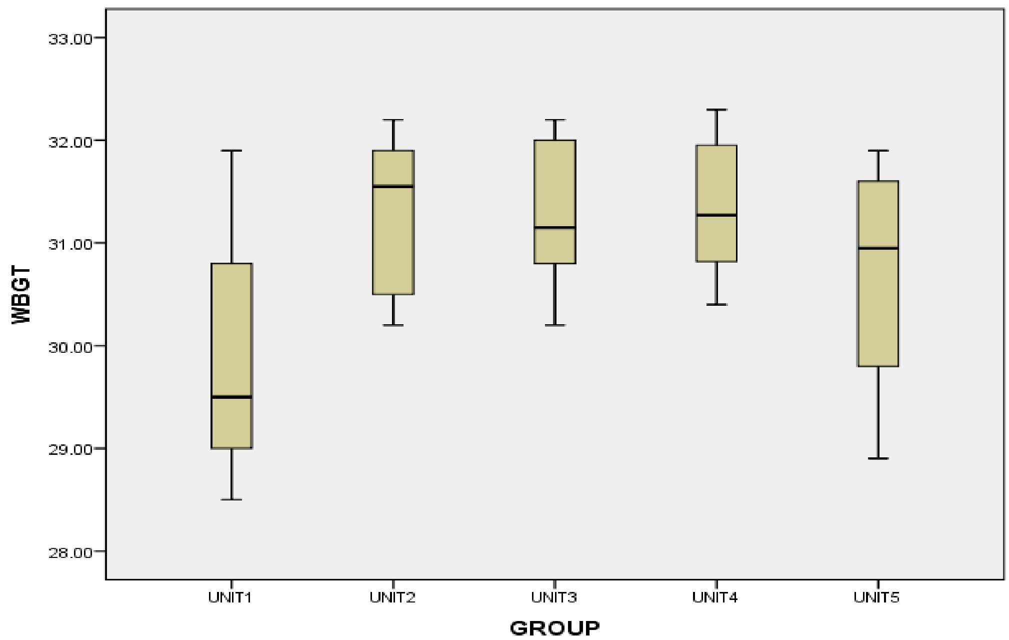
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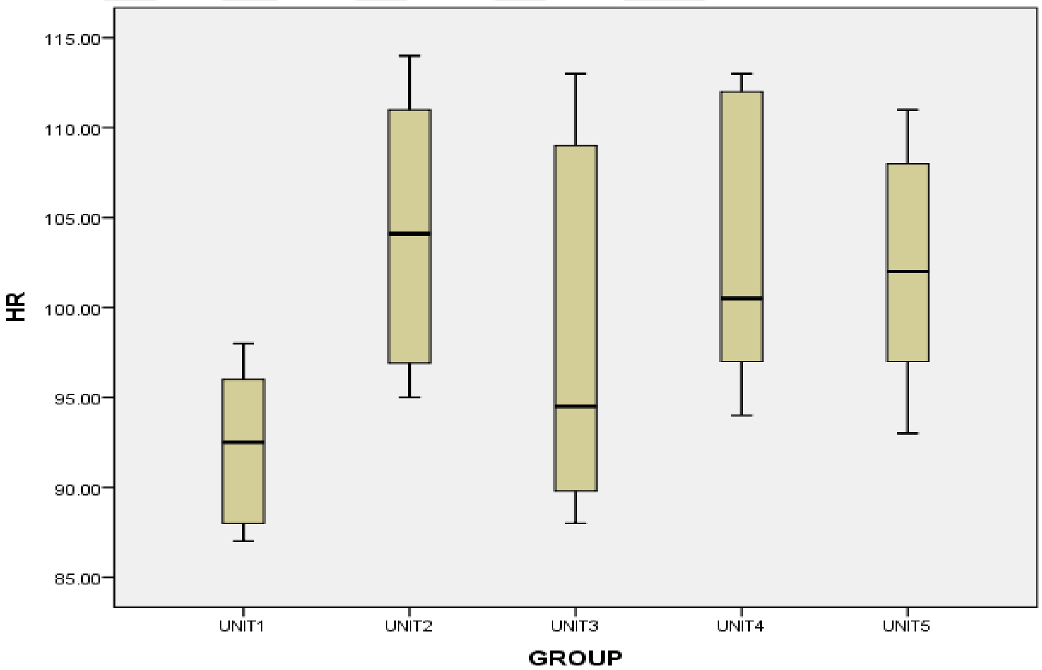
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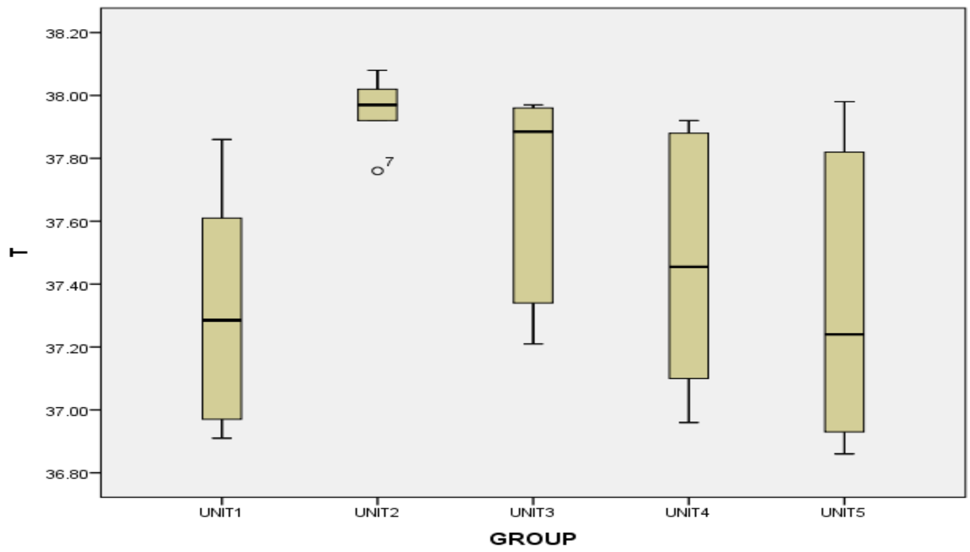
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7
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RESUME

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