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Effect of Environmental Changes in Working Heart Rate among Industrial Workers: An Ergonomic Interpretation

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Abstract**—**Occupational health hazard is a very common term in every emerging country. Along with the unorganized sector, most organized sectors including government industries are suffering from this affliction. In addition to workload, the seasonal changes also have some impacts on working environment. With this focus in mind, one hundred male industrial workers, who are directly involved to the task of Periodic Overhauling (POH) in a fabricating workshop in the public domain are selected for this research work. They have been studied during work periods throughout different seasons in a year. For each and every season, the participants working heart rate (WHR) is measured and compared with the standards given by different national and internationally recognized agencies i.e., World Health Organization (WHO) and American Conference of Governmental Industrial Hygienists (ACGIH) etc. The different environmental parameters i.e. dry bulb temperature (DBT), wet bulb temperature (WBT), globe temperature (GT), natural wet bulb temperature (NWB), relative humidity (RH), wet bulb globe temperature (WBGT), air velocity (AV), effective temperature (ET) are recorded throughout the seasons to critically observe the effect of seasonal changes on the WHR of the workers. The effect of changes in environment to the WHR of the workers is very much surprising. It is found that the percentages of workers who belong to the 'very heavy' workload category are 83.33%, 66.66% and 16.66% in the summer, rainy and winter seasons, respectively. Ongoing undertaking of this type of job profile forces the worker towards occupational disorders causing absenteeism. This occurrence results in lower production rates, and on the other hand, costs due to medical claims also weaken the industry's economic condition. In this circumstance, the authors are trying to focus on some remedial measures from the ergonomic angle by proposing a new work/ rest regimen and introducing engineering controls along with management controls which may help the worker, and consequently, the management also.

Keywords**—**Environmental changes, industrial worker, working heart rate, workload, occupational health hazard.

I. Introduction

JOB stress is becoming a worldwide epidemic. Stress-related injury claims on the job are gradually increasing. One cause of stress is the constant monitoring of employees from "how quickly they perform a task to the frequency and length of breaks". Unfortunately, companies are contributing to stress but doing little to help employees cope with it. In a running industry, it may be organized (i.e. mining, railway industry etc.) or unorganized (i.e. confectionary, small scale industry, road-side civil work etc.) where most employees are ignorant about the physiological limitations of their bodies. The physical and physiological capacity of a worker for continuing work in certain working ambience is unknown to the employer and employee too. This fact accelerates the likelihood of workers to be plagued by work-related health problems. During seasonal variations, the effect of almost the same workload for one particular group of people compared to another differs remarkably. In comparison with winter, the rainy and summer season become more stressful for the industrial workers. But in recent times, different research activities show that trained workers who can safely perform their jobs in a suitable environment are at reduced risk from work-related physical disorder. In this process, industrial ergonomists can help society by analyzing information about people, jobs, tools, equipment and workplace design to help employers to provide a safe and productive environment for employees. Research works of eminent scientists working in this field nationally and internationally are discussed below.

Schoofs et al. [1] researched working stress and tried to find out its impact on the working memory of industrial workers. They did two types of experiment on both male and female workers. The study tried to find out the effect of stress and emotional stimuli on the working memory of workers and concluded that the influence of stress on working memory appears not to be modulated by the emotionality of the employed stimuli. Shah et al. [2] stated that as society is passing through the era of competition among different industry regarding production targets, outturn and profit, job stress is becoming epidemic. As the goal of management and the worker is totally different, this problem becomes critical. The management wants to get maximum production at minimum cost and the worker tries to delay in job. But in this cold war, both suffer. Industrialists lose economic benefits and the workers lose their physical health, because they have to fulfill the targeted outturn, in the end. Their study was an attempt to combine and evaluate different theories on the above said issue and to find out a significant way to solve it. Biswas et al. [3] studied a very interesting subject. If any ergonomist discusses the workload of employees, he/she generally considers the workers of the organized sector and not about the unorganized sector such as the confectionary worker, who themselves would be continuously engaged in sweet making in a tiny shop and in front of an oven. The authors observed such unexplored occupations i.e.

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confectionary workers from the view point of working physiology and tried to evaluate the work stress involved in this occupation. Lowe and Pickup [4] studied one of the most debated concepts in ergonomics, i.e. workload. They established workload as a multidimensional concept which is dependent upon factors including the tasks, the context and the individuals. The authors study proposed to implement a toolkit to evaluate the compatibility of working atmosphere to achieve the highest performance level of individuals. Canjuga et al. [5] studied how Swiss industrial workers co-relate the control of job demand with working with a physiological disorder mainly on musculoskeletal disorders (MSD) like neck or back pain. They found that the type of work and continuous variation on the product as per the demand of the consumer as well as management greatly impacts on a worker's physiological and psychosocial health. They also established that mostly the demanding physical work along with psychosocial factors must be improved to save the workers from work related MSDs. Lovelace et al. [6] reviewed a very challenging topic related to the industrial health nowadays. In recent times, when most ergonomists are focused on the job stress of workers, the authors concentrated on the job stress of leaders and tried to find out the root causes of the stress and the remedy as well. They proposed a model which would practice and encourage self-leadership and introduce a shared leadership program for creating a positive and active work ambience. Kazmierczak et al. [7] described and examined the workload and performance level of workers assigned in truck-engine assembly work. They tried to collect data from observation, and after classification, interpret those on worker's performance, which would help to minimize both the economic and physical losses. Kivimaki et al. [8] tried to examine the relation between job stress and the effort reward imbalance and the risk of death from cardiovascular disease (CVD). The evidence from industrial workers suggest that sincere thinking should be done towards the prevention of work stress as this is the root cause of increasing the risk of cardiovascular mortality. Wells et al. [9] assessed spinal compression of industrial workers in connection with lower back pain (LBP) and other MSD. To assess the exposure, the authors concentrated on physical load and by-passing the single measurement method and suggested a "toolbox" approach which establishes the feasibility of a common exposure metric apart from several disparate measurement methods. Andrews et al. [10] selected an automobile assembly plant, considering the epidemiology and biomechanical approach for finding the best way to analyze the workload among workers. They stated that the questionnaire and checklist method are more effective for estimating peak physical load among workers, than the expensive video analysis method. As part of the study, they considered L4/L5 spine compression and shear force L4/L5 moment, trunk angel and hand load. Though there might be some negligible outcome variance between the two methods, the authors suggested that preparation of the questionnaire is very important for more accurate results.

The aims and objectives of this present research are:

- To collect environmental data of the worksite in detail.
- To record the WHR of every worker continuously throughout each shift during each season i.e., summer (March to June), rainy (July to October) and winter (November to February).
- To compare the different seasonal WHR values, identify any variation and determine possible ways to reduce workload among workers.

II. Methodology

A. Subject

100 male industrial workers who are directly involved in the task of POH in the mechanical wing of a fabricating industry in the public domain volunteered for this research work. All the subjects have a minimum three years of work experience, which means they are familiarized with the job. They are engaged in different mechanical operations like fitting, welding, oxy-cutting, manual material handling etc. and have no history of medical illness, according to the health records provided by the on-site clinic.

B. Tasks

In the fabricating department of a POH workshop, mechanical fitters play a major role; from initial inspection to final dispatch, they are connected with every stage of the job by measuring, marking, fitting and guiding the oxy-cutter and arc welder continuously. The oxy-cutters cut the materials (mostly mild steel) which are marked by the fitters, and due to their continuous presence in front of an oxy-acetylene flame with temperatures around 3300 °C, their working ambience is always very hot. The arc welder plays an identically significant part in the fabricating industry. The welder joins different metal parts as per the job requirements, and for this, they have to concentrate intensely on the task as a matter of safety, and in the case of any fault, major penalty charge sheet will be issued to them immediately. Along with the physical work load, the mental pressure for welders increases their incidence of occupational diseases.

C. Parameters

Environmental parameters (Direct).

i) DBT (°C):
ii) WBT (°C):
iii) NWB (°C):
iv) AV ($1ms^{-1}$):

Environmental parameters (Derived):

i) RH (%):
ii) WBGT (°C):
iii) ET (°C):

Physiological parameters (Direct):

i) WHR (beats per minute, bpm): It is defined as the number of heartbeats per unit of time, usually expressed as beats per minute, when a person is working or playing or exercising. In this research work, WHR is recorded continuously at five seconds intervals with a portable heart rate monitor (Sports Tester Polar Electro CS 400, Finland). The monitor is placed on the trans-thoracic region of the subject before going to work and is taken off after completion of job. The average WHR is calculated from the continuously monitored heart rate data.

TABLE I
A GLIMPSE ON THE SEASONAL VARIATION AND ITS EFFECT ON ENVIRONMENTAL PARAMETERS

Season		DB (°C)	WB (°C)	GT (°C)	NWB (°C)	WET BULB DEP	RH (%)	WBGT (°C)	AV (m/sec)	ET
Summer	Mean	33.46	29.22	33.53	28.63	4.33	72.36	30.1	0.1	30.33
	SD	2.47	1.72	2.91	1.78	1.38	7.88	1.99	0	1.78
Rainy	Mean	32.85	29.17	32.47	28.73	3.68	76.33	29.85	0.1	30.09
	SD	1.82	1.71	1.74	1.81	1.15	6.75	1.69	0	1.49
Winter	Mean	30.8	26.78	30.22	26.17	4.02	73.28	27.39	0.1	28.13
	SD	2.97	2.87	3.17	3.05	0.88	5.2	3.04	0	2.52

III. RESULTS

Table I clearly reflects the seasonal variation and its effect on the environmental parameters both direct and derived. As the table shows, the DB value gradually decreases from 33.46 °C to 32.85 °C from summer to the rainy season, and in winter season it reaches down to 30.8 °C. The relative humidly value of the worksite also differs during season changes. During summer, it has the mean value of 72.36% but in the rainy season it reaches up to 76.33% and in winter it falls down to 73.28%. In the case of the WBGT and ET values, we can see the same reflection.

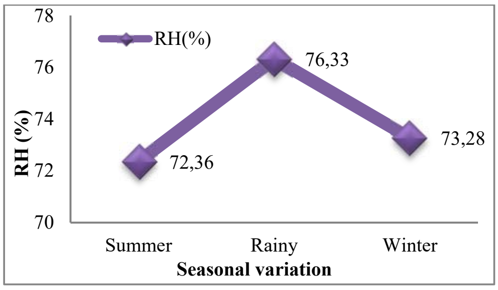

Fig. 1 A glimpse on the effect of seasonal variation on RH

Fig. 1 clearly shows the effect of seasonal variation on RH. From the mean value of 72.36% during summer it reaches at the value of 76.33 % in the rainy season and in the winter its mean value falls to73.28%.

Fig. 2 clearly demonstrates the effect of seasonal variation on WBGT. From the mean value of 30.1°C during summer, it reaches 29.85 °C in the rainy season, and falls to 27.39 °C in winter.

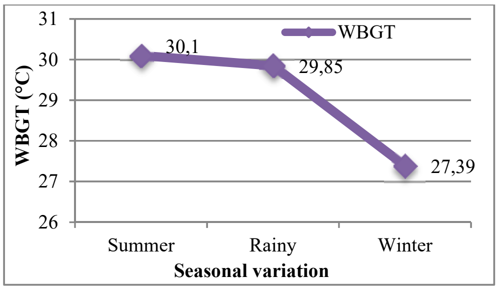

Fig. 2 A glimpse on the effect of seasonal variation on WBGT

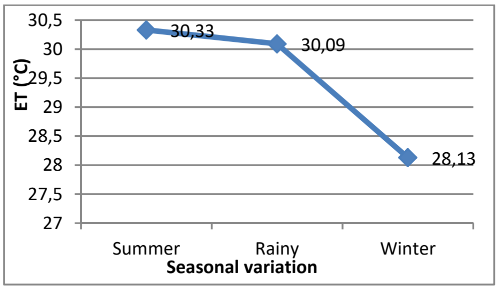

Fig. 3 A glimpse on the effect of seasonal variation on ET

Fig. 3 clearly illustrates the effect of seasonal variation on ET. From the mean value of 30.33 °C during summer, it reaches 30.09 °C in the rainy season and falls to 28.13 °C in winter.

TABLE II
A GLIMPSE ON THE EFFECT OF SEASONAL VARIATION ON WHR AND ITS RELEVANT TOWARDS STATISTICAL SIGNIFICANCE WITH THE ENVIRONMENT

Season		Fitter		Oxy-cutter		Welder	
		(≤ 40 Years)	(> 40 Years)	(≤ 40 Years)	(> 40 Years)	(≤ 40 Years)	(> 40 Years)
Summer	Mean	131.8	144	127	138	122	135
	SD	3.33	1.52	2.83	2.86	3.03	1.98
Rainy	Mean	126	139	125	133	118	131
	SD	2.63	3.9	3.39	3.56	3.11	2.65
Winter	Mean	119	131	117	128	111	124
	SD	3.16	4.16	4.09	2.17	2.65	3.88

If we look at Table II, we can understand the effect of seasonal variation of WHR of different categories of workers.

In summer season, the mean value of WHR of the senior fitters is 144 bpm, whereas in rainy season and winter season it falls down to 139 bpm and 131 bpm, respectively. These similar types of changes occur in each and every case of all categories of workers.

Table III reflects the significant difference between two sets of data in each of the cases. Here we can see that the variation of WHR during seasonal changes is significantly different from other sets of data and most of the cases the level of significance is < 0.01.

Table IV shows the changes in WHR of the different categories of worker due to the change in WBGT during seasonal variation. In the summer season, the mean value of the WHR of the senior fitters is 144 bpm when the mean WBGT value is 30.1°C, whereas in the rainy and winter seasons it falls to 139 bpm and 131 bpm, respectively Similar types of changes occur in each and every case and for all categories of worker. The following figure shows the relationship between WHR and WBGT value.

TABLE III
'P' – VALUE, (T TEST: HOMOSCEDASTIC, TWO TAILS) WHR OF ALL CATEGORIES OF WORKERS DURING DIFFERENT SEASONS

Sl. No:	Variables	'P' – Value, (t test: homoscedastic, two tail)
1	Fitters during summer and rainy season	<0.01
2	Fitters during summer and winter season	<0.01
3	Fitters during winter and rainy season	<0.05
4	Oxy-cutters during summer and rainy season	<0.05
5	Oxy-cutters during summer and winter season	<0.01
6	Oxy- cutters during winter and rainy season	<0.5
7	Welders during summer and rainy season	<0.1
8	Welders during summer and winter season	<0.1
9	Welders during winter and rainy season	<0.5

TABLE IV
CHANGES IN WHR DUE TO CHANGE IN WBGT DURING SEASONAL VARIATION

Season	WBGT	Working Heart Rate (bpm)					
		Fitter		Oxy-cutter		Welder	
		(≤ 40 Years)	(> 40 Years)	(≤ 40 Years)	(≤ 40 Years)	(> 40 Years)	(≤ 40 Years)
Summer	**30.1° C**	131.8	144	131.2	138	122	135
Rainy	**29.85°C**	131.1	139	125	133	118	131
Winter	**27.39°C**	119	131	117	128	111	124

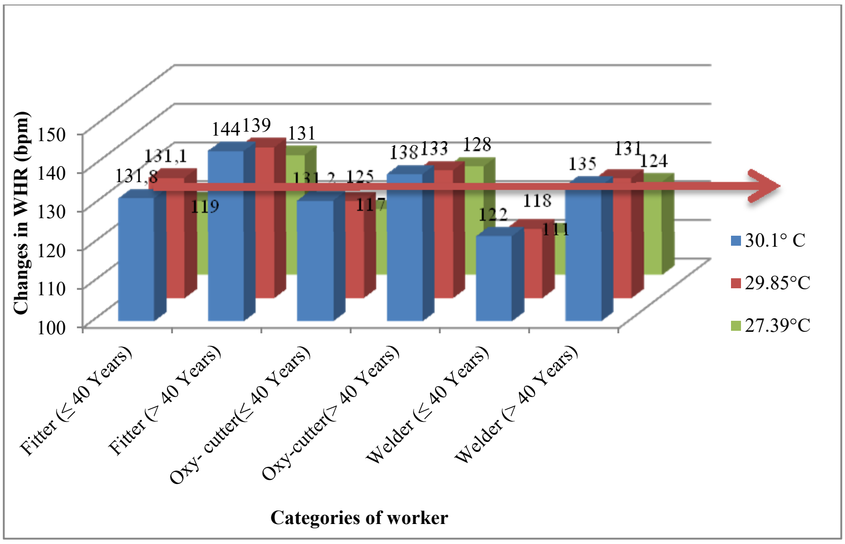

Fig. 4 Changes in WHR due to change in WBGT during seasonal variation

Fig. 4 clearly shows the adverse physiological effect due to seasonal variation. Here we can see that due to seasonal change i.e. summer, rainy and winter, the mean value of WBGT also differed from season to season and the mean WHR of the subjects also differed in connection to this phenomenon. Due to this seasonal variation, as the WHR differs, the workload categorization [11] is also changed. In the study, we adopted Astrand's classification [11] for WHR, where between 111 bpm to 130 bpm is considered the 'heavy' category and 131 bpm to 150 bpm is the 'very heavy' category. In Fig. 4 (as signified by the red arrow), it is clear that due to seasonal variations, the workload categorization of the worker is significantly changed though the nature of job is almost identical.

Table V illustrates the physiological workload of different categories of workers in different seasons. In summer, with the exception of the junior welders, all the other welders are in the category of very heavy workload group.

Table VI reflects the workload categorization of workers in different seasons. It is clearly understood that during the summer season, the workload of this POH shop is revised up to very heavy for almost all types of workers.

TABLE V
PHYSIOLOGICAL WORK LOAD CATEGORIZATION AND COMPARISON WITH OBSERVED VALUES

Parameter	Reference		Classification of workload				
			Light	Moderate	Heavy	Very heavy	Extremely heavy
WHR (beats/min)	Astrand		<90	90-110	111-130	131-150	151-170

Season	Fitters		Oxy-cutters		Welders	
	≤40 yrs (n=20)	>40 yrs (n=20)	≤40 yrs (n=15)	>40 yrs (n=15)	≤40 yrs (n=15)	>40 yrs (n=15)
Summer	131.8	144	131.2	138	122	135
Rainy	131.1	139	125	133	118	131
Winter	119	131	117	128	111	124

Remark

1. In summer, only junior welders fall in the heavy group and all others are in the very heavy group.
2. In the rainy season, junior oxy-cutters and welders are in the heavy group and all others are in the very heavy group.
3. In the winter season, only senior fitters are in the very heavy group and all others are in the heavy group.

TABLE VI
EFFECT IN WORKLOAD CATEGORIZATION DUE TO SEASONAL VARIATION

Season	Fitter		Oxy-cutter		Welder	
	(> 40 Years)	(≤ 40 Years)	(≤ 40 Years)	(> 40 Years)	(≤ 40 Years)	(> 40 Years)
Summer	Very heavy	Very heavy	Very heavy	Very heavy	Heavy	Very heavy
Rainy	Very heavy	Very heavy	Heavy	Very heavy	Heavy	Very heavy
Winter	Heavy	Very heavy	Heavy	Very heavy	Heavy	Heavy

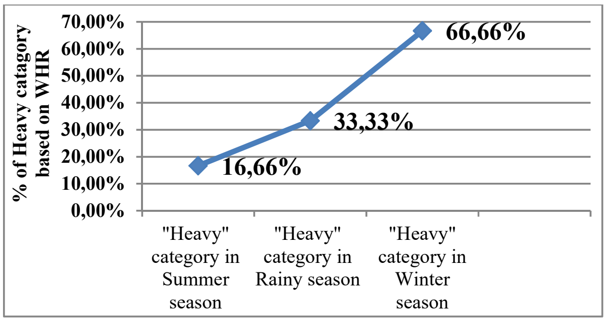

Fig. 5 (a) Effect of seasonal variation on 'Heavy' workload category

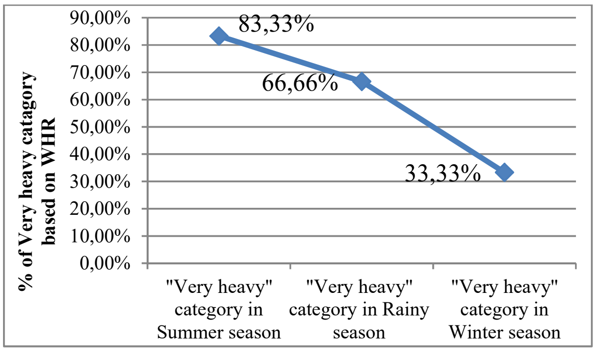

Fig. 5 (b) Effect of seasonal variations on 'Very heavy' workload category

Fig. 5 (a) exhibits the changes in workload category due to seasonal variations. The figure shows that there are only 16.66% of worker who are in 'heavy' category, while in the rainy season, the same figure increases to 33.33% and during winters it reaches up to 66.66%. On the other hand, as seen in Fig. 5 (b), it clearly shows that during the summer season 83.33% workers are in the 'very heavy' category, however, during the rainy season this figure falls to 66.66% and in winter it is only 33.33%. Thus, due to change in the environment in the work place, the WHR of the subjects changes and is reflected in the categorization of workload.

It is observed from Table VII that the mean ET value of the working site is 30.33°C, 30.09°C and 28.13°C in the summer, rainy and winter seasons, respectively. In the summer and rainy seasons, this value is above the permissible heat exposure limits for acclimatized personnel as recommended by WHO [12].

The recommended Work-rest regimen (proposed by ACGIH) [13] should be maintained to diminish the adverse effect of heat strain on working personnel.

Threshold Limit Values (TLV) [14] are based on the assumption that nearly all acclimatized, fully clothed workers with adequate water and salt intake should be able to function effectively under the given working conditions without exceeding a deep body temperature of 38°C (100.4°F). They are also based on the assumption that the WBGT Index of the resting place is the same or very close to that of the workplace. Where the WBGT of the work area is different from that of the rest area, a time-weighted average should be used [14]. These TLV's apply to physically fit and acclimatized individuals wearing light summer clothing. Accordingly, heavier clothing that impedes sweat or that has a higher insulation value may be a good option.

TABLE VII
PERMISSIBLE HEAT EXPOSURE LIMIT (RECOMMENDED BY WHO) [12] COMPARED WITH OBSERVED VALUES

Type of job	ET (°C) for non-Acclimatized personnel	ET (°C) for Acclimatized personnel	Observed ET (°C) value		
			Summer	Rainy	Winter
Light	30	32	**30.33**°C	**30.09°C**	**28.13°C**
Moderate	28	30			
Heavy	26.5	28.5			
Remarks			In the summer and rainy the value is above the limit but in winter it is within range.		

*Mean values given

TABLE VIII
ACGIH [13] THRESHOLD LIMIT VALUES FOR HOT ENVIRONMENTS, AS MEASURED IN THE WBGT INDEX

Work/rest regimen	**Threshold Limit Values for WBGT in °C (for acclimatized personnel)**			**Observed WBGT value** (acclimatized personnel, heavy workload)		
	Work Load					
	Light	**Moderate**	**Heavy**	**Summer**	**Rainy**	**Winter**
Continuous work	30.0°C	26.7°C	25.0°C			
75% work, 25% rest, each hour	30.6°C	28.0°C	25.9°C	30.1	29.85	27.39
50% work, 50% rest, each hour	31.4°C	29.4°C	27.9°C			
25% work, 75% rest, each hour	32.2°C	31.1°C	30.0°C			
Proposed work-rest regimen	During winter season75% work, 25% rest, each hour, in rainy season 50% work, 50% rest, each hour and in the summer season 25% work, 75% rest, each hour.					

* Mean values given

From the evaluated mean values of the WBGT of the working place (Table I), it is seen that in both the cases there should be followed a strict work-rest schedule. Table XIII shows that during the winter season, the optimal per hour work/rest ratio for workers is 75% work, 25% rest, while for the rainy season it is 50% work, 50% and the summer season is 25% work, 75% rest.

IV. DISCUSSIONS

A. Alteration of Work-Rest Cycle Due to Environmental Variation and Its Impact on Productivity

Although the working circumstances of this workshop are not modest, the energy cost of both the groups of fitters, oxy-cutters and welders are heavy in nature as observed earlier in this article. Higher energy demand of the task makes it harder to execute continuously at the expected pace. Environmental heat load in the field imposes extra load on the workforce. The mean ET value is above the permissible heat exposure limits as suggested by WHO [12]. As a consequence, the body of workers in the above 40 years of age group is observed to be affected much more than that of the junior age group.

Due to the hostile nature of the environment at the worksite, effective working hours should be less as compared to that of previous effective hours in respect to the work/rest scheduling recommended by ACGIH [13]. Thus, it is shown that environmental unfriendliness plays an important role in varying the productive hours of workers during a shift. This indicates that the general ambience of the environment in the work place is not humanizing but hostile. Consequently, a study should be made on rationalizing the environment so that the input parameters of the environment can be re-assessed.

Table IX indicates that due to possible changes of environment (the selective environmental parameters i.e., the GT and NWBT value may be decreased by 4.5% and 3.46%, respectively, then the value of WBGT will reach 27.7°C), the work/rest regimen may be shifted from 50% work/50% rest position to 75% work/25% rest position for the 'Heavy' category worker, which in turn satisfies the recommendation achieved through the Spitzer [15] rest allowance application.

TABLE IX
PROBABLE CHANGES IN THE ENVIRONMENTAL PARAMETERS AS A WHOLE

Parameters	Value (current level)	Value (accepted level)	Decrease in %
GT, °C	31.94	30.5	4.5
NWBT, °C	27.45	26.5	3.46

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