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SENSATION OF HEAT STRESS UNDER HOT ENVIRONMENTS OF WORKERS WITH DIFFERENT WORKLOADS IN OUT AND INDOOR CONDITIONS

[1]SALAH M. R, [2]MUNA M.M.

[1]occupational Health Safety Centre, Khartoum

[2]Institute Of Environmental Studies, University Of Khartoum

Corresponding author: SALAH M. R

ABSTRACT

The present research was carried out with the objective to assess the impact of thermal environment (indoors/outdoors) on the health workers carrying different workloads (heavy, moderate, light). The outdoor study targeted subjects working in building construction area in Khartoum. The indoor study targeted subjects working in textile and glassware factories at Khartoum industrial area. The control subjects were selected from those employed at the National Health Laboratory. Thermal physical measurements included: wet-bulb globe temperature (WBGT) and heat stress indices (HSI) and physiological strain index (put on a scale from 0 to 10, PSI). Allowable exposure time (AET) was calculated from HSI and mean recovery time (MRT). A questionnaire was designed to assess sensation of stress under hot environments. HSI was shown to decrease with the decrease in workload. The results showed that, **PSI** increased significantly (P <.01) with the increase of workloads for both outdoor and indoor subjects. On the psychophysical scale of thermal comfort sensation (+5 to -5), all groups were uncomfortable at the afternoon but were comfortable and within the thermoneutral zone at night. Negative correlations (P <0.01) were obtained among air temperature, air velocity and HSI, but positive correlations (P <0.001) between air, radiant heat or heat strain. It could be concluded that for workers with different loads, under hot thermal environments and with no compliance to the recommended Occupational Safety and Health Administration (OSHA, 1999) experience heat stress with various degrees.

KEYWORDS: Heat Stress, Hot Environment, Workload

INTRODUCTION

Thermal stress during work is the net thermal load that a worker may be exposed to the combined contribution of metabolic cost of work, environmental factors (air temperature, humidity, air velocity, and radiant heat exchange), and clothing requirements. Inadequate thermal stress may cause discomfort and adversely affect the performance, safety and harm to health. Occupational exposure to hot and cold environments may have an adverse effect on the performance, health, comfort of the workers (Tanaka, 2007). Such thermal conditions are observed in several outdoor jobs and indoor works. Extreme hot environments can overwhelm the body's coping mechanisms leading to a variety of serious and possibly fatal conditions (Azlis *et al*., 2007). Whenever, there is heat stress which is imposed on the human body from the surrounding thermal environment, there will be a resulting heat strain on the human body which may cause physiological reactions such as increased skin temperature, sweat production, increased heart rate and higher core temperature (Azlis *et al*., 2007).

Research has revealed that six major factors, among many others, determine the total thermal stress load of work in a hot environment: these are ambient air temperature, relative humidity, air speed, mean radiant temperature, clothing insulation and physical activity level (Epstien and Moran, 2006). Apart from physiological effects due to heat stress, a number of studies on performance in a hot climate have shown that both physical and mental performance can be negatively affected by a hot climate (Abeysekera,, 1988). The wet-bulb globe temperature (WBGT) is by far the most widely used heat stress index throughout the world. It was developed in the US Navy as part of a study on heat related injuries during military training (Jerry and Thomas, 2000)

MATERIALS AND METHODS

AREA OF STUDY

The present study targeted workers carrying different workloads (light, moderate and heavy) under different thermal environments at Khartoum city. Outdoor and indoor workers, selected outdoor workers were those working in an open area at ground floor, involved in cement mixing considered to carry out mild work; those in the second floor working under half-shaded roof were considered to perform moderate work, while those working on the third floor without roof were considered to perform heavy work. Indoor workers targeted those in textile and glassware industries. In the textile industry all were considered to carry heavy work. In the glassware industry workers were divided into three categories, as to carry light, moderate and heavy works. Measurements of the thermal environments at each study were carried out every 1 hour for 4 working days. The working day started at 8:00, and ended at 16:00 with a break of 1 hour in the morning (10:00 -11:00) and 30 minutes in the afternoon (13:00 13:30 pm). Classification for mild, moderate and heavy works was done in accordance with work-load assessment, (ACGIH 1992, Table 2.1).

Community Medicine & Public Health Insights
ISSN: XXX-XXX Volume – 1, Issue – 1, 2026
DOI:

TRESEARCH

2.1.2 SAMPLE SIZE

For estimation of the sample size the following formula was used:

$$n = t^2PQ/d^2$$

where:

n *=sample size*

Q *= 1-P*

t *= standard normal deviation (1.96)*

P *= proportion affected*

Q *= 1-P*

d *= degree of precision (0.05)*

2.2 TARGET SUBJECTS

Target subjects were those working either outdoor in building construction our inside factories, 84 participated in the study as explained above

2.3. MEASUREMENT OF THE THERMAL ENVIRONMENT

Thermal environment at each selected site were measured by using the standard instruments recommended by the WHO and the ILO (NIOSH, 1986). The instruments were placed at about 120 cm above ground (ACGIH, 2004).

2.3.1. DRY-BULB (AIR) TEMPERATURE:

Air temperature was measured by mercury thermometer in the range (-5 to 50°C). It was shielded from the sun and other radiant surfaces without restricting the air flow around the bulb (OSHA, 1999).

2.3.2. DRY AND WET-BULB TEMPERATURE (HUMIDITY)

In this type of psychrometer (sling psychrometer), two thermometers are mounted side by side in a frame fitted with a handle by which the device can be whirled through the air. The motion was arrested for reading of the thermometers, and continued until the thermometer readings became steady (Gagge *et al.,* 1974). The device is whirled once again and the readings of dry and wet-bulb temperatures were taken immediately. Then the relative humidity and vapor pressure were obtained from readings using psychrometric tables (Martin, 1970).

2.3.3 NATURAL WET-BULB TEMPERATURE

Natural wet-bulb temperature was measured by wet-bulb thermometer (mercury-in-glass). Its bulb is covered by cotton wick. The other end of the wick was immersed into a beaker filled with distilled water. The wick was wetted by direct application of water from a syringe for half an hour before each reading. The bulb of the thermometer was covered by wick and equal length of additional wick to cover the stem above the bulb (OSHA, 1999).

2.3.4. AIR VELOCITY:

The air velocity was determined through the cooling power of the moving air which is measured by the kata thermometer. The kata thermometer is a liquid alcohol in a glass thermometer with a large bulb and a stem with an upper reservoir. There are two marks on the stem, at the degrees of 125°F-130°F. kata factor was 538 (for the thermometer used in this study). Mean air velocity was then calculated by eq. (1).

2.4 HEAT STRESS INDICES

Two heat stress indices were then calculated using these parameters. The heat stress index (HSI) and the wet bulb globe temperature (WBGT).

2.4.1 HEAT STRESS INDEX

calculated using the equations: (1) Air velocity (ft/min):

V (ft/min) = [[H/ (T-ta) – a] / b] ………………………….(1)

Where:

V = air velocity, in ft/min

H is cooling power = kata factor / Average cooling time(sec)

ISSN: XXX-XXX Volume – 1, Issue – 1, 2026
DOI:

kata factor = 538

ta = air temperature (Dry) °F

T, a, b are constant

T = 127.5°F

a and b depend on the air movement: for low air movement (stagnant air):

a= 0.061 and b = 0.0139 for high air velocity (moving air):

a= 0.011 and b= 0.017

(2) HEAT STRESS INDEX (HSI):

HSI % = Ereq / Emax X 100 ……………………………… (2)

Where:

Ereq = the amount of heat which must be dissipated by the body, through evaporation of sweat, in order to maintain thermal balance according to the following equation: Heat balance equation

Ereq = M ± R ± C ……………………………………. (3)

Where

M= is metabolic heat. It is a by-product of the body's activity which depends on type of work-load category. It was determined by averaging metabolic rates as follows: Resting: Average M =100 kcal/hr. (400 But /hr).

Light work: Average M =150 kcal/hr. (600 But /hr)

Moderate work: Average M = 250-300 kcal/hr. (1000-1200 But /hr).

Heavy work : Average M = 400-450 kcal/hr. (1600-1800 But /hr)
R (BTU/hr) = 17.5(MRT-95) …………………………….. (4)

Where:

R= Radiant heat load

MRT°F = $[(tg + 460)^4 + 1.03X10^8 V^{0.5} (tg – Ta)]^{0.25}$ - 460……... (5)

Where:

V = air velocity (ft/min)

95 = skin temperature °F

C = Convective heat load

C (BTU/hr) = 0.756 $V^{0.6}$ (ta -95) …………………………..... (6)

Emax: represents the maximum heat loss which can be achieved under this condition and is calculated by the following equation.

Emax = 2.8 $V^{0.6}$ (42-PPA) ……………………………………… (7)

Where

V = air velocity (ft/min)

PPA = partial pressure of water vapour (mmHg).

The HSI as an index therefore was related to strain, essentially in terms of body sweat, for values between 0 and 100. At HSI =100, evaporation required is the maximum that achieved, and thus represents the upper limit of the evaporative zone. For HSI >100, there was body heat storage, and allowable exposure times are calculated based on a 1.8°C rise in core temperature. For HSI<0 there is mild cold strain for example, when workers recover from heat strain, (table 2.) (OSHA, 1999).

2.5 WORK LOAD ASSESSMENT

The metabolic heat production is a combination of heat generated by basal metabolism plus heat generated through activity. For practical purposes, the value for metabolic heat load can be estimated by: Observing the tasks performed (through a complete cycle of operation). Attributing a value of metabolic heat output, according to the nature of the work performed (work load), through the use of tables found. These can be for instance: Tables which give value for different tasks (or

ISSN: XXX-XXX Volume – 1, Issue – 1, 2026
DOI:

groups of tasks) already considering heat production by basal metabolism (table 2.2). Tables which allow the determination of total metabolic heat load by adding partial values, attributed to different movements of the body plus the value corresponding to basal metabolism, as tables (2.2.1), (2 .2.2).

Table 2. Heat stress index (HSI) values interpretation

HIS (%)	**Effect eight hour exposure**
- 20	Mild cold strain (e.g. recovery from heat exposure)
0	No thermal strain
10 - 30	Mild to moderate heat strain. Little effect on physical work but possible effect on skilled work
40 - 60	Severe heat strain, involving threat to health unless physically fit. Acclimatization required.
70 - 90	Very severe heat strain. Personnel should be selected by medical examination, ensure adequate water and salt intake.
100	Maximum strain tolerated daily by fit acclimatized young men.
Over 100	Exposure time limited by rise in deep body temperature.
Source (Parsons, 1998)	

Table (2.2). Estimate of metabolism

	Activity	**Btu/hr**	**Kcal/hr**
Light work	Sitting quietly	400	
	Sitting, moderate arm and trunk movement	400 - 550	113 - 138
	Sitting, moderate arm and leg movement	550 - 650	138 - 163
	Sitting, light work at machine or bench	550 - 650	138 - 163
Moderate work	Sitting, heavy arm and leg movement	650 - 800	163- 200
	Standing, light work and some walking	650 -750	163 - 188
	Standing, moderate work and some walking	750 - 1000	188 - 250
	Walking, moderate lifting or pushing	1000- 1400	250- 350
Heavy work	Intermittent, heavy lifting, pushing or pulling	1500 - 2000	375 - 500
	hardest sustained work	2000- 2400	500 - 600

Source (WHO, 1977).

Table (2.2.1): Assessment of workload

Average values of metabolic rate during different activities

Body position and movement	**Kcal/min**
Sitting	0.3
Standing	0.6
Walking	2.0 – 3.0
Walking up hill	add 0.8 Per meter (yard) rise

ISSN: XXX-XXX Volume – 1, Issue – 1, 2026
DOI:

Table (2.2.2) Average values of arms

Type of work		Average	Range
Hand work	light	0.4	0.2 – 1.2
	heavy	0.9	
Work with one arm	light	1.0	0.7 – 2.5
	heavy	1.8	
Work with both arms	light	1.5	1.0 – 3.5
	heavy	2.5	
Work with body	light	3.5	
	moderate	5.0	2.5 – 15.0
	heavy	7.0	
	very heavy	9.0	

Source (WHO, 1977).

An even more simplified approach is to consider three basic categories of work load: light, moderate and heavy, and if necessary for calculations attribute average energy expenditure as follows:

Light work: average M = 150 kcal /hr. (600 Btu/hr)

Moderate work: average M = 250 – 300 kcal /hr. (1000- 1200 Btu/hr).

Heavy work: average M = 400 – 450 kcal /hr. (1600- 1800 Btu/hr).

Resting: average M = 100 kcal /hr. (400 Btu/hr).

Examples of work load categories:

2.7.1 THERMAL COMFORT AND TEMPERATURE SENSATION

Questions about temperature and thermal comfort sensations were included in the diary. The respondents were asked to express their temperature sensation using a psychophysical random scale (Fig) ranging from (+15) for hot to (-15) for cold, with in between intervals (+10) for warms (+5) for slightly worm (0) for neutral (-5) for slightly cool, and (-10) for cool. The subjects also expressed their thermal comfort sensation on another psychophysical random scale ranging from (+3) for very comfortable to (-3) for very uncomfortable with in between intervals of (+1) for comfortable (0) for indifferent and (-1) uncomfortable.

Table 3.2. A Dry, natural wet, globe bulbs and wet bulb globe temperature index (WBGT) for heavy load workers

time	Dry bulb (ta) temp	Natural wet bulb temp	Globe (tg) temp	WBGT temp
08:00	34.0	28	35	30.1
09:00	34.0	28	35.5	30.25
10:00	35.0	29	36.5	31.25
11:00	36.6	31	37.5	32.95
12:00	37.0	30	38.5	32.55
13:00	38.3	30	40	33.0
14:00	40.6	31	41	34.0
15:00	37.8	30	42	33.6
16:00	35.6	30	38	32.4

ISSN: XXX-XXX Volume – 1, Issue – 1, 2026
DOI:

TRESEARCH

Table 3.2.B Dry, natural wet, globe bulbs and wet bulb globe temperature index (WBGT) for moderate load workers

time	Dry bulb (ta) temp	Natural wet bulb temp	Globe (tg) temp	WBGT temp
08:00	33.9	21.5	35	25.55
09:00	33.9	21.5	35	25.55
10:00	36.1	26.0	37	29.3
11:00	37.8	28.0	38.5	31.15
12:00	38.9	27.0	41	31.2
13:00	40.3	30.0	42	33.6
14:00	40.6	28.5	44.5	33.3
15:00	40.6	28.0	44	32.8
16:00	42.2	43.0	44.5	43.45

Table 3.2.C Dry, natural wet, globe bulbs and wet bulb globe temperature index (WBGT) for light load workers

time	Dry bulb (ta) temp	Natural wet bulb temp	Globe temp (tg)	WBGT temp
08:00	36.1	25.5	36	28.65
09:00	36.1	25.5	36	28.65
10:00	36.1	24.5	37.5	28.4
11:00	39.4	24.5	39	28.85
12:00	37.2	24.5	39.5	29.0
13:00	38.9	25.5	41	30.15
14:00	39.4	26	41	30.5
15:00	41.7	38	43	39.5
16:00	41.7	40	44.5	41.35

Table 3.3.2.1 Mean Globe, dry and natural wet bulb temperatures (°C) at study2

values	Dry bulb temperature (°C)			Natural wet bulb temperature (°C)			Globe temperature (°C)			Wet bulb globe temperature (°C)		
	H	M	L	H	M	L	H	M	L	H	M	L
Mean	36.53	38.23	38.4	29.67	28.2	28.22	38.22	40.2	39.7	32.23	31.77	31.67
±SEM	1.0	0.96	0.71	0.35	1.98	1.9	0.76	1.23	0.97	0.44	1.67	1.58
Max	40.6	40.6	41.7	31	43	40	42	44.5	44.5	34	43.45	41.35
Min	34	33.9	36.1	28	21.5	24.5	35	35	36	30.1	25.55	28.4

H = heavy work load, M= moderate work load, L = light work load

Table 3.23.2.2 Mean Wet temperature (°C), air velocity (m/s) and humidity (%)

	Wet bulb temperature (°C)			**Air velocity m/s**			**Humidity %**		
	H	M	L	H	M	L	H	M	L
Mean	23.3	20.11	21.44	0.42	0.54	0.42	33.08	17.76	20.84
±SEM	1.08	0.46	0.4	0.05	0.07	0.03	3.26	1.2	0.91
Max	27	22	23	0.61	0.92	0.56	51.89	21.44	24.17
Min	17	18	20	0.27	0.36	0.35	15.97	10.41	15.82

ISSN: XXX-XXX Volume – 1, Issue – 1, 2026
DOI:

Table 3.2.C Dry, natural wet, globe bulbs and wet bulb globe temperature index (WBGT) for control load workers at control study

Time	Dry bulb (ta) temp	Natural wet bulb temp	Globe temp (tg)	WBGT temp
08:00	26.7	28	28	27.87
09:00	26.7	27.5	27.5	27.42
10:00	26.7	26.5	27.5	26.72
11:00	26.7	16	27	19.27
12:00	26.7	16	27	19.27
13:00	25	15.5	27	18.75
14:00	31.1	18.5	32	22.46
15:00	32.2	18.5	33	22.77
16:00	32.2	18.5	33	22.77

Table 3.3.2.3 Mean Globe, dry and natural wet bulb temperatures (°C) of the control group

	Dry temp	Globe temp.	Natural temp.	Wet temp.	Air velocity	Humidity %	WBGT temp
Mean	28.2	29.1	20.56	21.28	1.18	35.97	23.03
±SEM	0.87	0.85	1.64	0.36	0.1	4.5	1.13
Max	32.2	33	28	22.5	1.52	54.87	27.84
Min	25	27	16	19	0.72	17.87	18.75

Table 3.3. Psychological scale for predicted mean vote (PMV):

Temperature Sensation		**Thermal comfort Sensation**	
Hot	+3	Very uncomfortable	- 10
Warm	2	Uncomfortable	-5
Slightly warm	1	Indifferent	0
Neutral	0	Comfortable	+5
Slightly cool	-1	Very comfortable	+10
Cool	-2		

* Predicted mean vote (PMV) for thermal comfort and temperature sensation of subjects during summer 2011 for three different groups

For outdoor, figures 3.3.1A, 3.3.1B, 3.3.1C show subjective thermal comfort and temperature sensation expressed for heavy, moderate and light work repectively. On the psychophysical scale of thermal comfort sensation, the heavy work group was not affected by the thermal environment (0) at 8:00 and at 10:00 (PMV=2-1). During the night the group were within the neutral zone (0) at 19:00 and comfortable (+5) at 22:00 (PMV=3.5) (table 3.4.2A). The moderate work group was felt comfortable (+5) at 8:00, but were not affected (0) at 10:00 while felt uncomfortable (-5) during the afternoon (PMV=-3.85). The group was within comfortable (+5) zone at 19:00 while felt very comfortable (+10) at 22:00 (table 3.4.2B). The light work group was not affected by the thermal environment during morning (0) but felt uncomfortable (-5) during the afternoon (PMV=-3.3). During the night they were either unaffected (0.0) at 19:00 or comfortable (+5) at 22:00 (table 3.4.2C).

On the psychophysical random scale of temperature sensation, the indoor workers represented PMV for temperature sensation as follows: The heavy work group was felt slightly warm (+1) at 8:00 and at 10:00, but felt hot (+3) during the afternoon (PMV=2.89). During the night they were either unaffected (0.0) at 19:00 or comfortable (+1) at 22:00 (3.4.1). The moderate work group was within the neutral (0) zone at 8:00, but felt slightly warm (+2) at 10:00. However, felt hot (+3) during the afternoon but within neutral (0) zone at 19:00 and slightly warm (+1) at 22:00 (table 3.4.1). The light work group was within neutral (0) at early morning but felt slightly warm (+1) at 10:00. However, the group was within the warm (+2)

ISSN: XXX-XXX Volume – 1, Issue – 1, 2026
DOI:

TRESEARCH

zone during the afternoon. At night the group were either within the neutral zone at 19:00 but slightly warm (+1) at 22:00 (table 3.4.1).

Table 3.4.1 (PMV) heavy, moderate, light workload and control

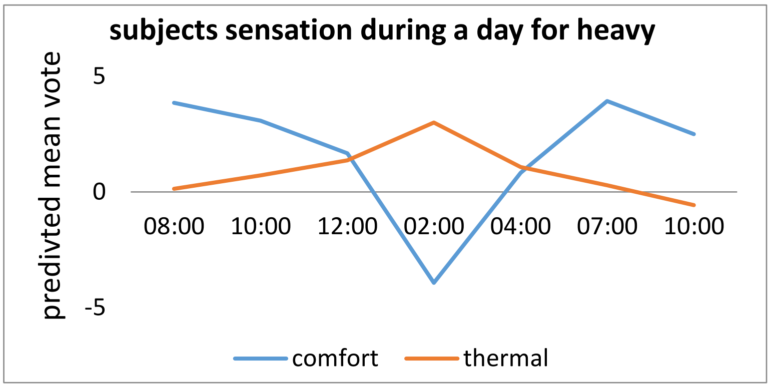
	Time	Thermal comfort	Temperature sensation
Heavy work load group	8:00	2.0±1.26	1.33±0.44
	10:00	1.0±1.38	1.0±0.42
	12:00	1.5±1.01	1.44±0.36
	14:00	-0.5±1.49	2.89±0.1
	16:00	-1.0±1.55	0.89±0.43
	19:00	0.5±1.0	0.56±0.32
	22:00	3.5±1.01	0.78±0.34
Moderate work load group	8:00	3.85±1.35	0.17±.2
	10:00	1.54±0.84	1.42±.32
	12:00	1.15±0.97	1.17±.42
	14:00	-3.85±1.11	3.0±0.0
	16:00	1.15±0.97	1.67±.36
	19:00	5.77±0.92	0.58±.28
	22:00	5.77±1.2	-0.17±.11
Light work load group	8:00	0.0±1.43	0.71±.44
	10:00	0.0±1.01	1.0±.45
	12:00	-.71±0.66	1.71±.39
	14:00	0.0±1.75	2.0±.49
	16:00	-3.3±0.97	2.0±
	19:00	2.14±1.71	0.71±.6
	22:00	2.86±1.71	1.0±.64
Control without work load group	8:00	2.0±1.76	0.9±0.49
	10:00	0.5±1.11	1.9±0.38
	12:00	1.0± 0.9	2.2±0.39
	14:00	-2.0±1.5	2.8±0.19
	16:00	-3.0±1.8	2.5±0.38
	19:00	0.5±1.3	0.9±0.39
	22:00	4.0±1.18	0.1±0.36

Valued are mean ±SEM

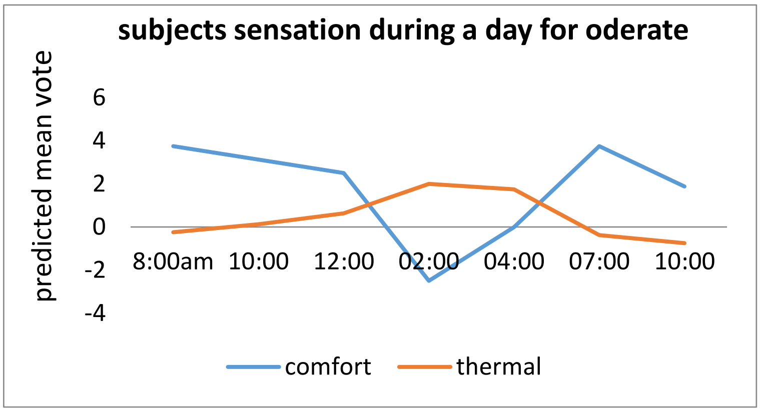
Community Medicine & Public Health Insights
ISSN: XXX-XXX Volume – 1, Issue – 1, 2026
DOI:

Figures 3.3.1. PMV for Subjects exposed to outdoor workloads.

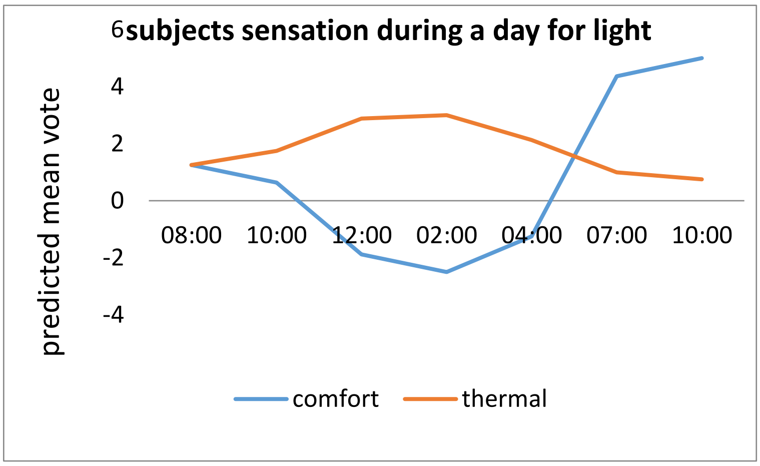
Top-box:



Middle-box:



Bottom-box:



For outdoor. Diagram for a subject groups exposed to a hot ambient temperature during summer working day. **Top**: thermal/ comfortable /uncomfortable sensation plotted against time of day under heavy work load. **Middle-box**: thermal/ comfort sensation plotted against time day under moderate work load. **Bottom:** thermal/ comfort sensation plotted against time of day under light work load

For indoor: Figures 3.3.2 show subjective thermal comfort and temperature sensation expressed by the indoor workers. On the psychophysical scale of thermal comfort sensation, the heavy work group was not affected by the thermal environment (0) at 8:00 and at 10:00 (PMV=2-1). During the night the group were within the neutral zone (0) at 19:00 and comfortable (+5) at 22:00 (PMV=3.5) (table 3.4.2A). The moderate work group was felt comfortable (+5) at 8:00, but were not affected (0) at 10:00 while felt uncomfortable (-5) during the afternoon (PMV=-3.85). The group was within comfortable (+5) zone at 19:00 while felt very comfortable (+10) at 22:00 (table 3.4.2B). The light work group was not affected by the thermal environment during morning (0) but felt uncomfortable (-5) during the afternoon (PMV=-3.3). During the night they were either unaffected (0.0) at 19:00 or comfortable (+5) at 22:00 (table 3.4.2C).

On the psychophysical random scale of temperature sensation, the indoor workers represented PMV for temperature sensation as follows: The heavy work group was felt slightly warm (+1) at 8:00 and at 10:00, but felt hot (+3) during the afternoon (PMV=2.89). During the night they were either unaffected (0.0) at 19:00 or comfortable (+1) at 22:00 (table 3.4.2A). The moderate work group was within the neutral (0) zone at 8:00, but felt slightly warm (+2) at 10:00. However, felt hot (+3) during the afternoon but within neutral (0) zone at 19:00 and slightly warm (+1) at 22:00 (table 3.4.2B). The light work group was within neutral (0) at early morning but felt slightly warm (+1) at 10:00. However, the group was within the warm (+2) zone during the afternoon. At night the group were either within the neutral zone at 19:00 but slightly warm (+1) at 22:00 (table 3.4.2C).

Table 3.4.2A. (PMV) heavy workload group

Heavy work load group		
Time	Thermal comfort	Temperature sensation
8:00	2.0±1.26	1.33±0.44
10:00	1.0±1.38	1.0±0.42
12:00	1.5±1.01	1.44±0.36
14:00	-0.5±1.49	2.89±0.1
16:00	-1.0±1.55	0.89±0.43
19:00	0.5±1.0	0.56±0.32
22:00	3.5±1.01	0.78±0.34

Table 3.4.2B. (PMV) moderate workload

Moderate work load group		
Time	Thermal comfort	Temperature sensation
8:00	3.85±1.35	0.17±.2
10:00	1.54±0.84	1.42±.32
12:00	1.15±0.97	1.17±.42
14:00	-3.85±1.11	3.0±0.0
16:00	1.15±0.97	1.67±.36
19:00	5.77±0.92	0.58±.28
22:00	5.77±1.2	-0.17±.11

Values are means ±SEM

Table 3.4.2C. (PMV) Light workload group

Light work load group		
Time	Thermal comfort	Temperature sensation
8:00	0.0±1.43	0.71±.44
10:00	0.0±1.01	1.0±.45
12:00	-.71±0.66	1.71±.39
14:00	0.0±1.75	2.0±.49
16:00	-3.3±0.97	2.0±
19:00	2.14±1.71	0.71±.6
22:00	2.86±1.71	1.0±.64

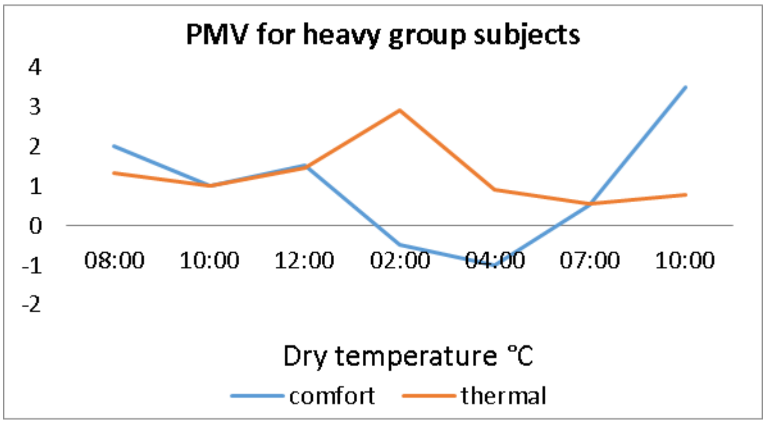
Table 3.4.3. (PMV) Control workload

Control without work load group		
Time	Thermal comfort	Temperature sensation
8:00	2.0±1.76	0.9±0.49
10:00	0.5±1.11	1.9±0.38
12:00	1.0± 0.9	2.2±0.39
14:00	-2.0±1.5	2.8±0.19
16:00	-3.0±1.8	2.5±0.38
19:00	0.5±1.3	0.9±0.39
22:00	4.0±1.18	0.1±0.36

Values are mean ±SEM

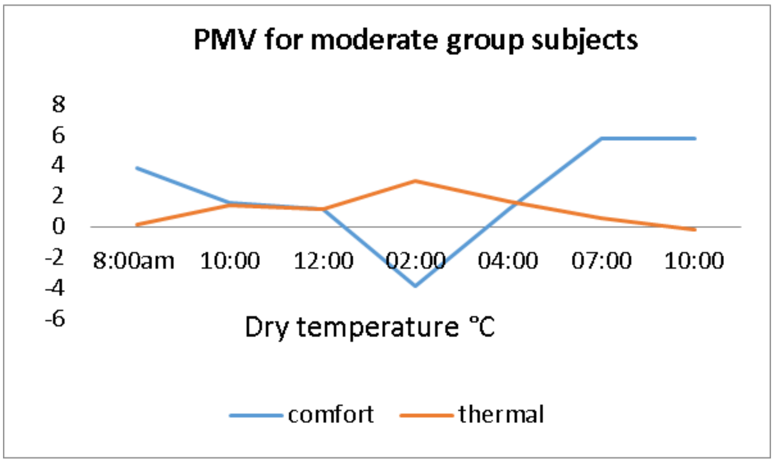
Fig 3.3.2. PMV for Subjects exposed to indoor workloads.

Top-box:



ISSN: XXX-XXX Volume – 1, Issue – 1, 2026
DOI:

Middle-box:



Bottom-box:

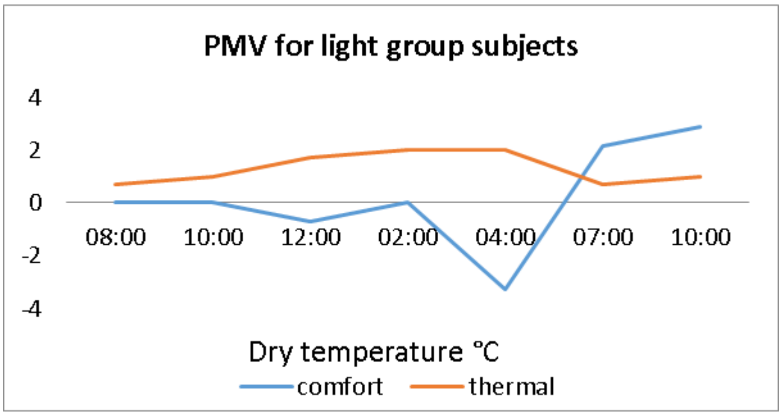
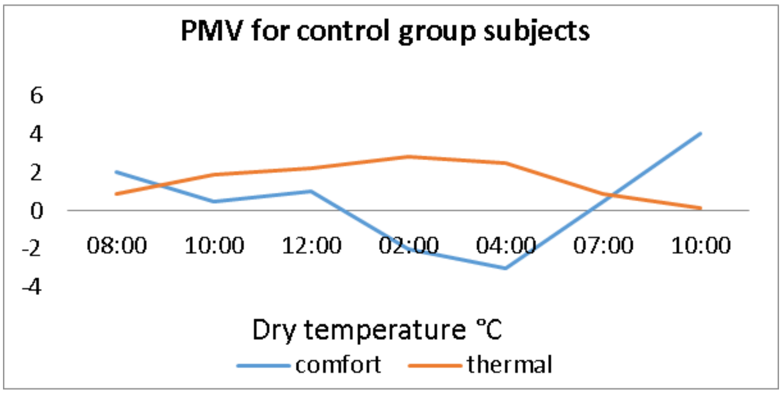


Diagram for a subject groups exposed to a hot ambient temperature during summer working day. ***Top***: thermal/ comfortable /uncomfortable sensation plotted against time of day under heavy work load. ***Middle-box****:* thermal/ comfort sensation plotted against time day under moderate work load. ***Bottom*:** thermal/ comfort sensation plotted against time of day under light work load

C. CONTROL STUDY

Figure 3.3.3 shows subjective thermal comfort and temperature sensation expressed by the control group. On the psychophysical scale of thermal comfort sensation, the control group showed comfortable (PMV=2) response in the early morning and neutral (0) at 10:00 but uncomfortable during the afternoon (-5) (PMV=-2). During the night the group was not affected (0) by the thermal environment at 19:00 and was comfortable (+5) at 22:00. On the psychophysical random scale of temperature sensation, the control group, the group was within neutral (0) zone at 8:00 but felt warm (+2) at 10:00. During the afternoon the group felt hot (+3), while at night they were within the neutral (0) zone at but felt slightly warm (+1) at 19:00 and 22:00 respectively (table 3.4.3).

Fig 3.3.3. PMV for Subjects exposed to control workloads.



3.5 WET BULB GLOBE TEMPERATURE (WBGT)

The wet bulb globe temperature was about 30°C at 08:00 for all types of outdoors work, increased gradually till 10:00 then increased for heavy, moderate and light work, but decreased for the control between 12:00 and 15:00 then increased slowly

ISSN: XXX-XXX Volume – 1, Issue – 1, 2026
DOI:

for outdoor (table 3.5.1). For indoors (table 3.5.2) same trends were observed but slight increase at 15:00 for moderate and light workload. Generally, WBGT measurements were higher for heavy, followed by moderate and light compared with the control for both outdoor (Fig 3.4.1) and indoor (Fig 3.4.2), with outdoors showing higher values than indoors.:

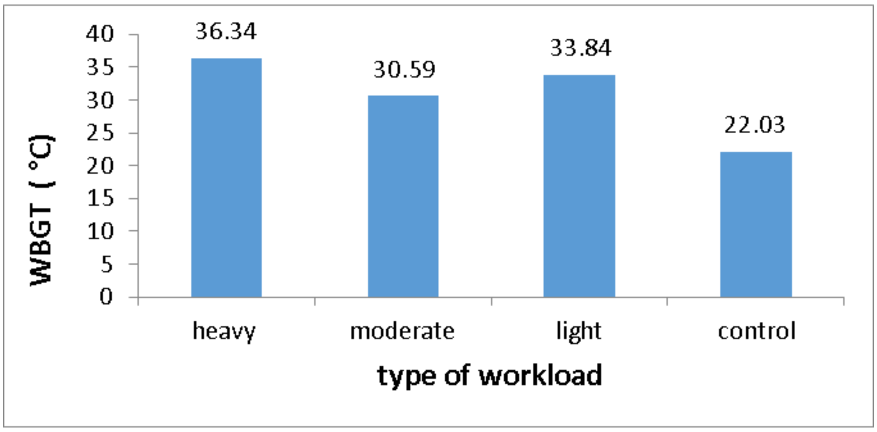
Table 3.5.1. WBGT during the working hours for outdoors

	Wet bulb-globe temperature for different groups			
time	Heavy	**Moderate**	**Light**	**Control**
08:00	30.2	26.9	26.65	27.87
09:00	31.2	27.95	27.15	27.42
10:00	34.4	28.55	31.65	26.72
11:00	33.4	29.35	35.65	19.27
12:00	35.4	30.9	36.6	19.27
13:00	36.0	31.35	36.55	18.75
14:00	42.65	33.1	37.65	22.46
15:00	42.1	33.4	36.5	22.77
16:00	41.75	33.9	36.2	22.77

Table 3.5.2. WBGT during the working hours for indoors

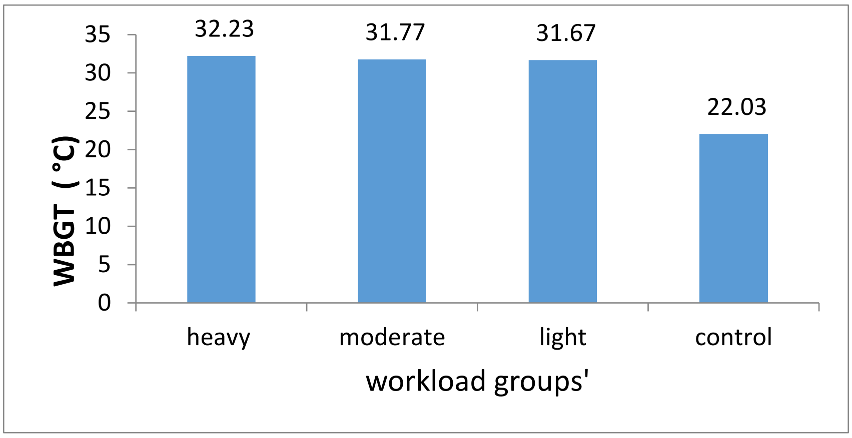
	Wet bulb-globe temperature for different groups			
time	**Heavy**	**Moderate**	**Light**	**Control**
08:00	30.1	25.55	28.65	27.87
09:00	30.25	25.55	28.65	27.42
10:00	31.25	29.3	28.4	26.72
11:00	32.95	31.15	28.85	19.27
12:00	32.55	31.2	29.0	19.27
13:00	33.0	33.6	30.15	18.75
14:00	34.0	33.3	30.5	22.46
15:00	33.6	32.8	39.5	22.77
16:00	32.4	43.45	41.35	22.77

Fig 3.4.1. Mean wet bulb globe temperature during the working day in three locations at construction building site at outdoors



ISSN: XXX-XXX Volume – 1, Issue – 1, 2026
DOI:

Figure 3.4.2. Mean wet bulb globe temperature during the working day in three locations at indoor sites



WORKING HOURS PRACTICE:

All the participants (workers) in the study were working for one shift. Outdoor, indoor and control workers were working between 6 ¾ -7 hours/day (table 3.20.2). The work-rest cycle considered those workers had taken one hour for breakfast at 10:00 am and 10 minutes at 1:00 pm for prying. Without undertaking work/rest regimen system.

3.5.1 WORK-REST REGIMEN TAKEN FROM WET-BULB GLOBE TEMPERATURE RESULTS

Table 3.6.1 and table 3.6.2. Shows the work-rest regimen cycle calculated according to the standards recommended by OSHA (table 2.2.) using the allowable exposure time and mean recovery time, obtained from WBGT index results (table 3.5.1; table 3.5.2). For each hour workers carrying heavy loads had 25% work and 75% rest throughout the day. For moderate, work-rest regimen calculated was 100% work and zero rest at 08:00, 75% work and 25% rest (between 09 and 10 am), 50% work and 50% rest (between 11 and 12:00) , 25% work and 75% rest for the rest of the day. For the light work group, it is 100% work till 09:00, 50:50 at 10:00 then 75:25 for the rest of the day. For the control it is 100 % works and no rest for each hour throughout the day. For the indoor groups, heavy work load group working hours and rest is the same as for the outdoors. The light and control groups have no resting for each hour. For the moderate workload group there is no rest till 09:00, at 11:00 the ratio is 25:75 then reversed to 75:25 for the rest of the day. It is generally shown that groups of different workloads for outdoors, the work to rest ratio is 25:75 for heavy work, for moderate the ratio is 50:50, for light is 75:25, and for the control is 100:0. For indoors the only difference was moderate which treated as heavy workload.

Table 3.6.1. Work-rest regimen for different workloads at outdoors (calculated from WBGT)

Groups →	Heavy		Moderate		Light		Control	
work/rest Time → ↓	Work % /hr	Rest % /hr	Work % /hr	Rest % /hr	Work % /hr	Rest % /hr	Work % /hr	Rest % /hr
8:00	25	75	100	0.0	100	0.0	100	0.0
9:00	25	75	75	25	100	0.0	100	0.0
10:00	25	75	75	25	50	50	100	0.0
11:00	25	75	50	50	25	75	100	0.0
12:00	25	75	50	50	25	75	100	0.0
13:00	25	75	25	75	25	75	100	0.0
14:00	25	75	25	75	25	75	100	0.0
15:00	25	75	25	75	25	75	100	0.0
16:00	25	75	25	75	25	75	100	0.0

*Work-rest cycle % each hour during working day.

ISSN: XXX-XXX Volume – 1, Issue – 1, 2026
DOI:

Table 3.6.2. Work-rest regimen for different workloads for indoor (calculated from WBGT)

Groups →	Heavy		Moderate		Light		Control	
work/rest → Time ↓	Work % /hr	Rest % /hr	Work % /hr	Rest % /hr	Work % /hr	Rest % /hr	Work % /hr	Rest % /hr
8:00	25	75	100	0.0	100	0.0	100	0.0
9:00	25	75	100	0.0	100	0.0	100	0.0
10:00	25	75	75	25	100	0.0	100	0.0
11:00	25	75	25	75	100	0.0	100	0.0
12:00	25	75	25	75	100	0.0	100	0.0
13:00	25	75	25	75	100	0.0	100	0.0
14:00	25	75	25	75	100	0.0	100	0.0
15:00	25	75	25	75	25	75	100	0.0
16:00	25	75	25	75	25	75	100	0.0

*Work-rest cycle % each hour during working day.

Fig 3.5.1 Mean work-rest regimen taken/hour for different workloads under outdoor conditions

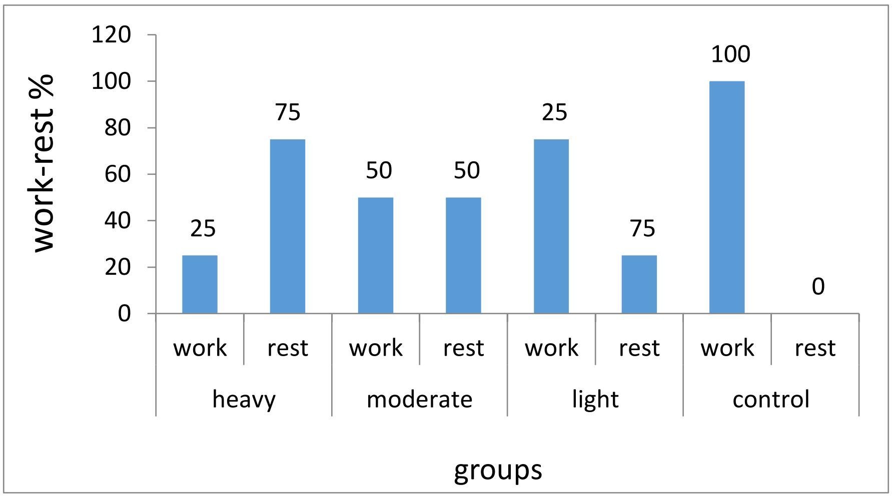
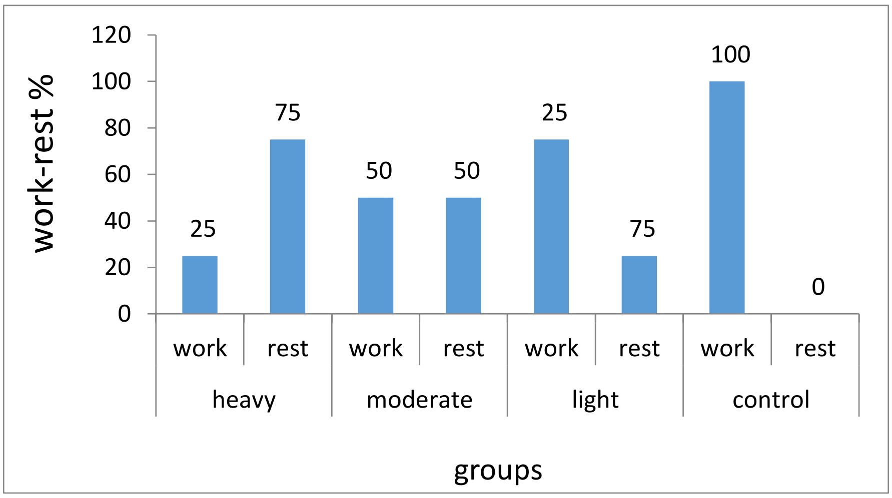


Fig 3.5.2 Mean work-rest regimen taken/hour for different workloads under indoor conditions



ISSN: XXX-XXX Volume – 1, Issue – 1, 2026
DOI:

3.6 HEAT STRESS INDEX (HSI)

Heat stress index (HSI) was shown to be high at 08:00 (725%) then decreased sharply reaching a minimum at 16:00 (229%) for the heavy workload at outdoors (table 3.7.1) and the mean of HSI was 385% /8 hours working day (figure), which was higher than the maximal (100%) strain tolerated daily by fit acclimatized young men (Exposure time limited by rise in deep body temperature) according to interpretation of Parsons (1998) TLV values (table 2.1). For moderate and light workloads HSI fluctuated at low levels throughout the day. HSI between 0.0-40% (daily mean 16%) for moderate , and between 0.0-48% (daily mean 28.6%) for light group. interpretation represents no thermal strain, mild to moderate heat strain and Little effect on physical work but possible effect on skilled work.

For indoors heavy work load HSI (table 3.7.2) started at low levels (91.68) declined sharply reaching a maximum (232%) and a daily mean was (143%) at 16:00 (table) which indicated maximum strain tolerated daily by fit acclimatized young men. Moderate workload showed a lower peak at 12:00 (64%) and a higher peak at 13:00 (109%) and 87.8% as a daily mean which indicated very severe heat strain, personnel should be selected by medical examination, ensure adequate water and salt intake. Light and control showed lower HSI with the control group showing lower values (figure). This represents no thermal strain. Generally HSI decreased with the decrease in workloads for both outdoor (Fig 3.6.1) and indoor (Fig 3.6.2) environments; however, with the outdoor environment it increased slightly with the light workload compared to the moderate.

3.6.1 CORRELATION REGRESSION BETWEEN HSI AND AIR VELOCITY

Correlation regression between HSI and air velocity showed that HSI was significantly ($P < 0.001$) negatively correlated ($r = -0.55$) with air velocity (Fig 3.7.1A) for outdoor conditions. For indoor conditions, same results were obtained where HSI was significantly ($P < 0.001$) negatively correlated ($r = -0.701$) with air velocity (Fig 3.7.2A).

Table 3.7.1. Heat stress index for different workloads outdoor

Hours	Heat stress index (HSI)			
	Heavy	**Moderate**	**Light**	**control**
08:00	725.41	3.277	36.464	4.448
09:00	635.30	-0.597	40.628	1.047
10:00	578.57	2.414	-9.391	2.716
11:00	300.14	4.235	4.4748	-3.457
12:00	256.20	20.349	31.530	-3.457
13:00	253.84	19.934	47.898	-0.113
14:00	242.91	40.392	29.158	7.571
15:00	254.35	19.569	28.470	10.795
16:00	209.14	34.538	48.416	10.795
mean ±SEM	383.98 ±63.36	16.01 ±4.64	28.63 ±6.09	3.37 ±1.72

ISSN: XXX-XXX Volume – 1, Issue – 1, 2026
DOI:

Table 3.7.2. Heat stress index for different workloads indoors

Time	Heat stress index (HSI)			
	Heavy	Moderate	Light	control
08:00	91.68	80.078	52.854	4.448
09:00	105.79	80.078	52.854	1.047
10:00	121.35	86.174	66.568	2.716
11:00	141.55	90.099	58.729	-3.457
12:00	142.70	64.559	65.323	-3.457
13:00	123.16	109.468	82.594	-0.113
14:00	124.94	88.025	88.316	7.571
15:00	203.79	83.675	74.221	10.795
16:00	232.74	108.560	87.570	10.795
Mean ±SEM	143.07 ±14.47	87.86 ± 4.42	69.89 ±4.4	3.37 ±1.72

Figure 3.6.1: Mean of HSI for outdoor conditions

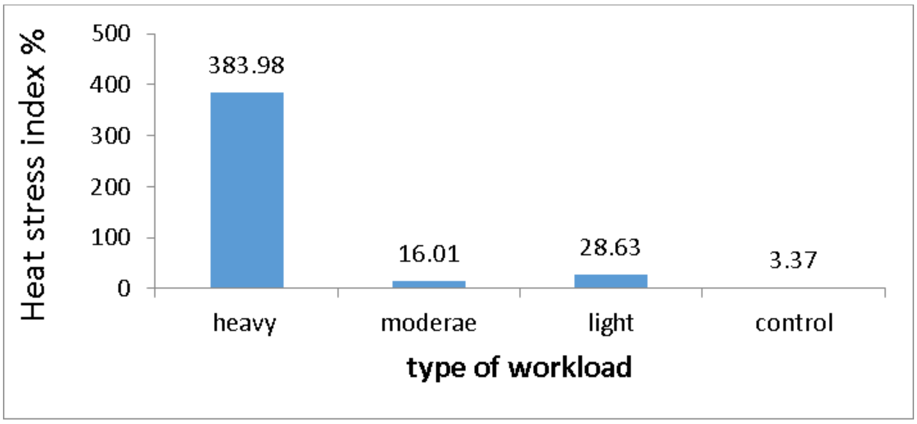
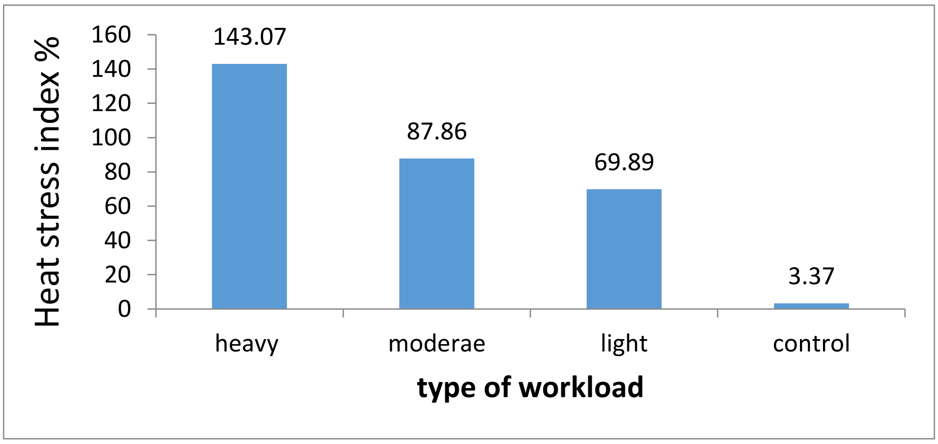


Figure 3.6.2: Mean of HSI for indoor condition



ISSN: XXX-XXX Volume – 1, Issue – 1, 2026
DOI:

TRESEARCH

3.6.2 ALLOWABLE EXPOSURE TIME (AET, HR), MEAN RECOVERY TIME (MRT, HR) CALCULATED FROM HSI UNDER OUTDOOR AND INDOOR THERMAL ENVIRONMENTS

Table shows the work-rest regimen that must be followed by authorities which calculated according to HSI obtained using equation (8) for the allowable exposure time and equation (9) for the mean recovery time. It can be shown that the allowable exposure time (AET) and mean recovery time (MRT) decreased steadily from 08:00 to 14:00 for the heavy workload only under outdoor (table 3.8.1) and indoor thermal environments (table 3.8.2). At 15:00 both AET and MRT increased, but decreased for MRT at 16:00 for the outdoor. For the indoor both AET and MRT decreased steadily throughout the day. For the moderate, light and control, continuous work could be carried out throughout the working day (HSI was <100%).

when comparing out and indoor thermal environments for the mean allowable exposure time and mean recovery time for heavy workload, it was shown that AET and MRT were higher for the outdoor than the indoor with MRT showing higher values than AET (Fig 3.8.).

Table 3.8.1 Allowable exposure time (AET/ hr), Mean recovery time (MRT/ hr) for the different workloads at outdoor thermal environments

workload	heavy		moderate		light		control	
Time	AET at Work	MRT at rest	AET at Work	MRT at rest	AET at Work	MRT at rest	AET at Work	MRT at rest
8:00	0.17	1.19	-	-	-	-	-	-
9:00	0.16	1.15	-	-	-	-	-	-
1000	0.14	1.10	-	-	-	-	-	-
11:00	0.16	0.84	-	-	-	-	-	-
12:00	0.15	0.67	-	-	-	-	-	-
13:00	0.15	0.65	-	-	-	-	-	-
14:00	0.15	0.61	-	-	-	-	-	-
15:00	0.16	0.70	-	-	-	-	-	-
16:00	0.18	0.59	-	-	-	-	-	-

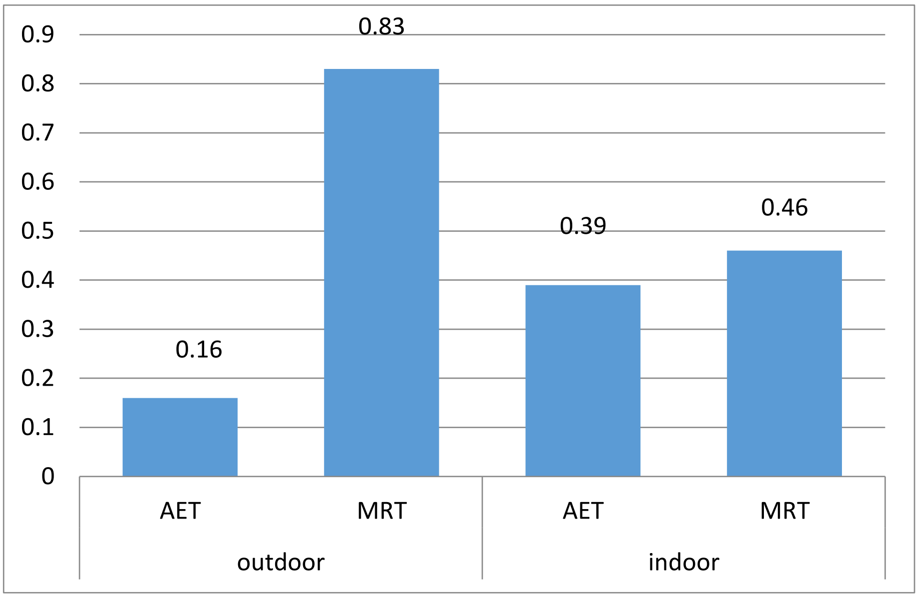
*(-): continuous AET

Table 3.8.2 Allowable exposure time (AET, hr), Mean recovery time (MRT, hr) for the different workloads at indoor thermal environments

workload	heavy		moderate		light		control	
Time	AET at Work	MRT at rest	AET at Work	MRT at rest	AET at Work	MRT at rest	AET at Work	MRT at rest
8:00	0.87	0.22	-	-	-	-	-	-
9:00	0.53	0.35	-	-	-	-	-	-
1000	0.40	0.44	-	-	-	-	-	-
11:00	0.32	0.54	-	-	-	-	-	-
12:00	0.30	0.51	-	-	-	-	-	-
13:00	0.36	0.31	-	-	-	-	-	-
14:00	0.35	0.30	-	-	-	-	-	-
15:00	0.20	0.66	-	-	-	-	-	-
16:00	0.21	0.84	-	-	-	-	-	-

*(-): continuous AET

Fig 3.8. Comparison between out and indoor for the mean allowable exposure time and mean recovery time for heavy workload



DISCUSSION

In the present study and according to WBGT index for indoor and outdoor working environment, it was found that outdoors showed values above the comfortable zone for the continuous 8 hours of work especially during the afternoon for both heavy and moderate workloads. Same was obtained for indoor of the glass textile factory heavy workload. This could be attributed to the interactions of variable factors defining outside conditions such as ambient, radiant, humidity and air velocity. For indoors, use of different cooling systems might explain the differences in the above comfort zone obtained inside the textile factory compared with the other factories. In general WBGT measurements were higher for heavy, followed by moderate and light compared with the control for both outdoor and indoor, with outdoors showing higher values than indoors. This could also be related to interactions of above physical factors and modifications of indoor conditions using fans or air conditioning. Temperature sensation showed that both indoors (45%) and outdoors (47%) subjects felt very hot, while ~35-40% felt hot for the indoors and control groups respectively. 60% of the control group were not affected by the thermal environment.

The heat stress (HSI) as defined by the ratio of evaporation required to maintain heat balance. The HSI as an index therefore is related to strain, essentially in terms of body **sweat,** for values between 0 and 100. At HSI =100, represents the upper limit of the evaporative zone. The value of HSI was found to be inversely related to the air velocity. Similarly, it was stated that, the quantity of heat transferred to man from the environment is dependent upon the thermal conductivity of both atmosphere and clothing and upon the thickness of the still air layers (Fanger, 1973). The allowable exposure time (AET) and mean recovery time (MRT) were calculated according to (OSHA, 1999). For heavy work only, AET should be matched with the mean recovery time (MRT) for both indoor and outdoor conditions. This was not the case in this study where sensation of thermal discomfort was experienced with most workers carrying heavy work under outdoor conditions. Symptoms of thermal stress injuries were felt most during summer as thirst for outdoor, fatigue, and headache. Work hazards were related mostly to heat and dust. Accident complaints were expressed more by the outdoor groups and related to falling objects. It is concluded that, it is better to rely upon physiological measurements as a means of evaluating the tolerance limits of very hot environments. It is recommended that, the risk of heat-related illnesses can be reduced by: Engineering controls to provide a cooler workplace, Safe work practices to reduce worker exposure, Training employees to recognize and prevent heat illnesses. Heat reduction can also be achieved by using power assists and tools that reduce the physical demands placed on a worker. The worker should be allowed to take frequent rest breaks in a cooler environment (ACGIH, 2002).

Hot jobs should be scheduled for the cooler part of the day, and routine maintenance and repair work in hot areas should be scheduled for the cooler seasons of the year. Rather than be exposed to heat for extended periods of time during the course of job, workers should, wherever possible, be permitted to distribute the workload evenly over the day and incorporate work-rest cycles. Work-rest cycles give the body an opportunity to eliminate excess heat and lessen the production of internal body heat, and provide greater blood flow to the skin (NOISH-2003). Cold areas must be provided for rest and recovery as close to the hot work environment as possible. Individual work periods should not be lengthened in favor of prolonged rest periods. Work-rest cycles are the greatest benefit to the worker (EHS, 2003, NOISH, 2003).

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