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# THERMOREGULATION RESPONSES OF WORKERS IN HOT ENVIRONMENTS UNDER OUT AND INDOOR CONDITIONS WITH DIFFERENT WORKLOADS

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## ABSTRACT

The present study targeted workers carrying different workloads (light, moderate and heavy) under different thermal environments of Khartoum state; the objective was to assess the impact of thermal environment (indoors/outdoors). Outdoor subjects were those working in building construction while indoor subjects were working in textile and glassware factories. The control subjects were selected from those employed at the National Health Laboratory. Parameters measured were: body temperature, heat strain (PSI), fluid intake, urine specific gravity and sweating rate. The results showed that body temperatures increased significantly ($P < 0.01$) during and after work compared to before work and were higher with subjects with heavy workloads and moderate than light and control groups and were higher for indoor than outdoor subjects. Significant positive correlations ($P < 0.001$) were obtained between body temperatures and heat strain. Water intake was found to be positively correlated ($P < 0.001$) with sweat rate and urine volume. Sweat rates increased with PSI.

**KEYWORDS:** Thermoregulation, hot environment, workload

## INTRODUCTION

Thermal balance is achieved by the total thermoregulatory response, in such a way as to minimize physiological strain, heat is gained from the environment and is produced by metabolism. This overall heat load must be dissipated to maintain a body temperature of 37°C, a process called thermoregulation (Abderrezak and James, 2002). One of the characteristic features of industrial exposure to heat today is learning over time to match the body's capability to maintain a thermal balance with the environment, including voluntary reduction in the metabolic generation of heat when necessary (Jerry and Thomas, 2000). The thermal gradient established by the evaporation of sweat is critical for the transfer of heat from the body to the environment. During exercise in hot climates, evaporation of sweat is the main avenue for heat dissipation. It is the only means for cooling the body when ambient temperature exceeds skin temperature (Bar-Or, *et al*., 1980; Falk *et al*., 1992). Dehydration commonly accompanies exercise in warm, humid conditions, when fluid replacement is inadequate. It complicates heat exhaustion and heat stroke. It occurs when water intake is insufficient to replace losses in urine, breath and eating. Physiological response to heat stress and exercise heat exposure produces progressive changes in thermoregulation that involve sweating, skin circulation, thermoregulatory set point, cardiovascular alterations, and endocrine adjustments (Helen *et al*, 2002). People carrying out heavy labour outdoors in heat radiation from strong sunlight during the hottest season are likely to be most at risk (Kjellstorm, et al 2009). Indoor workplaces are also affected as small workshops and even factories in low and middle income countries seldom provide air cooling systems. (Kjellstorm, *et al*., 2011; Lemake, *et al*, 2011).

## MEASUREMENT OF THERMAL ENVIRONMENT

## 2 AMBIENT TEMPERATURE

**Standard instruments were used r**ecommended by the WHO and the ILO (el Batawi, 1984, Wenzel *et al*., 1989, NIOSH, 1986, ACGIH, 1986). For indoor the measurements, instruments were placed at about 120 cm above ground (el Batawi, 1984, ACGIH, 1986). For outdoor measurements, a dry bulb thermometer was shielded to protect its bulb against sun or other infra-red radiation sources. Air speed was measured using a kata thermometer (casella T 6412) and a hot wire anemometer (silicon Anemometer Type- ISA-31).

## 1-2 HEAT STRAIN

A physiological heat strain index includes a combination of heart rate and body temperature was taken as an index of heat strain for use to monitor heat strain during continuous exercise (work). Physiological strain was evaluated for subjects in the study. The physiological strain index (PSI) was calculated according to Moran *et al*. (1998) The equation used was:

$$PSI = 5 * (Tri - Tr0) / (39.5 - Tr0) + 5 * (HRi - HR0) / (180 - HR0)$$

Where:

Tri and HRi are measurements of body temperature and heart rate of the subjects taken at any time during the heat exposure.

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Tr0 and HR0 are the seated resting values of body temperature and heart rate prior to beginning the work.

## PHYSIOLOGICAL MEASUREMENTS

### 2.7.2. FLUID INTAKE

Fluid consumption was determined by giving a cup with capacity of 400 ml was given to each subject to measure the amount of water drunk. Additional fluid intake (e.g. tea, coffee, soft drinks etc) consumed during the shift was also recorded. Volume of urine voided was measured.

### 2.7.3 HYDRATION STATUS

Hydration status was determined by measuring the specific gravity (SG) of urine. Samples collected from subjects during a working day in a weighted empty container. Weight of the samples with its container was determined. The volume of the urine sample was determined in measuring cylinder.

Specific gravity (SG) was calculated by the following formula:

Weight of the urine sample = (The weight of the urine sample with its container - the weight of the empty container)

Specific gravity (SG) = weight / volume

(For confirmation, SG was checked using a handheld, urine refractometer).

### 2.7.4. SWEATING RATE

Amounts of sweat produced were evaluated by monitoring the body weight lost by calculating appropriate fluid intake and output correction (during working day) was done. Water losses due to sweat was calculated as follows:

Sweat loss = (pre-shift nude weight – post-shift nude weight) + (water consumed – urine excreted). (WHO, 1977)

## RESULTS

### 3.1 MEASUREMENTS OF THERMAL ENVIRONMENTS

Measurements of thermal environments were taken for workers for the two study areas (outdoors and indoors) the parameters included globe, dry and wet bulb temperatures, air temperature and humidity. For outdoors subjects with light workload at ground unshaded floor were exposed to high air temperature, high humidity and lower air velocity than those working in the second floor under half-shaded conditions. For heavy load workers were exposed to mild low temperature, less wind velocity and high humidity. The conditions were better for moderate work load group who were exposed to lower temperature, less wind velocity but higher humidity (Table 3.1.1).

For indoors, heavy load workers were exposed to high air temperature, lower air velocity but high humidity. The moderate workload groups were exposed to low air temperature, and higher wind velocity but lower humidity. The light work group experienced, less air temperature, air velocity and humidity (Tables, 3.1.2). The control group was exposed to lower air temperature, low air velocity but higher humidity compared to outdoor and indoor conditions (Table 3.1.3).

**Table 3.1.1** Wet temperature (°C), air velocity (m/s) and humidity (%) for outdoor

| | **Wet bulb temperature (°C)** | | | **Air velocity m/s** | | | **Humidity %** | | |
|---|---|---|---|---|---|---|---|---|---|
| | H | M | L | H | M | L | H | M | L |
| **Mean** | 20.78 | 16.33 | 21.06 | 0.13 | 3.42 | 2.89 | 17.75 | 17.58 | 22.80 |
| **±SEM** | 0.41 | 0.61 | 0.34 | 0.03 | 0.57 | 0.36 | 1.44 | 2.14 | 0.80 |
| **±SD** | 1.23 | 1.83 | 1.01 | 0.8 | 1.71 | 1.07 | 4.32 | 6.41 | 2.39 |
| **Max** | 22 | 17 | 22.5 | 0.22 | 7.04 | 4.68 | 27.76 | 28.74 | 24.95 |
| **Min** | 19 | 15 | 19 | 0.02 | 1.23 | 1.31 | 12.93 | 11.30 | 17.42 |

**Table 3.1.1** Wet temperature (°C), air velocity (m/s) and humidity (%) for outdoor

| | 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 |

**Table 3.1.3** Wet temperature (°C), air velocity (m/s) and humidity (%) for control group

| | Wet temperature (°C) | Air velocity (m/s) | Humidity % |
|---|---|---|---|
| **Mean** | 21.28 | 1.18 | 35.97 |
| **±SEM** | 0.36 | 0.1 | 4.5 |
| **Max** | 22.5 | 1.52 | 54.87 |
| **Min** | 19 | 0.72 | 17.87 |

## 3.3 PHYSIOLOGICAL MEASUREMENTS

### 3.3.1 BODY TEMPERATURE

For outdoor thermal environment, body temperature increased significantly (P <0.01) with heavy work during work, for moderate work, light work and the control the significant increase (P <0.01) was observed only after work. Comparing the workloads, subjects with heavy workload,showed the highest (P <0.01) increase for before and during work, while subjects with moderate workload showed the highest (P <0.01) body temperature after work (table 3.3.1.1).

For indoor subjects with heavy workload showed significantly (P <0.01) lower body temperature before than during or after work, however, for moderate and light before and after work, subjects showed significant (P <0.01) reduction in body temperature. For the control, before and during work subjects showed significantly (P <0.01) lower body temperature. Comparison for the different workloads under indoor conditions showed that subjects with moderate and light works showed significant (P <0.01) body temperature before work, while during work subjects with heavy and light work showed significantly (P <0.01) higher temperature than moderate and control subjects. Same observations were obtained for after work, where moderate and control showed the lowest body temperature (table 3.3.1.2).

### CORRELATION/ REGRESSION BETWEEN AIR TEMPERATURE AND BODY TEMPERATURE

When air temperature (independent variable) was regressed against body temperature (dependent variable), a significant (P <0.001) positive correlation was obtained ($y = 0.0149x + 35.672$). For indoor the correlation was also significant (P <0.001) and positive ($y = 0.1295x + 32.15$)

### CORRELATION/ REGRESSION BETWEEN HUMIDITY AND BODY TEMPERATURE

When humidity (independent variable) was regressed against body temperature (dependent variable), a significant (P <0.001) positive correlation was obtained ($y = 0.0149x + 35.672$) ( for outdoors workers. For indoor the correlation was also significant (P <0.001) but negative ($y = 0.0217x + 36.628$).

**Table 3.3.1. 1** Body temperature for among and between different workloads (before, during and after work) for outdoor group

| Groups with different workloads | Core body temperature °C (±SEM) | | |
|---|---|---|---|
| | Before work | During work | After work |
| Heavy | $36.28±0.17^b$ | $37.1±0.21^a$ | $36.57±0.22^b$ |
| Moderate | $35.98±0.12^c$ | $36.6±0.19^b$ | $37.08±0.23^a$ |
| Light | $35.38±0.2^c$ | $35±0.97^c$ | $36.05±0.2^b$ |
| Control | $35.39±0.25^c$ | $35.78±0.18^c$ | $36.06±0.18^b$ |
| P-value | .002 | .000 | .007 |

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abcValues within the same rows and column bearing different superscript vary significantly at P<0.05

**Table 3.3.1.2** Body temperature comparison for among and between different workloads (before, during and after work) for indoor group

| Groups with different workloads | Core body temperature °C (±SEM) | | |
|---|---|---|---|
| | Before work | During work | After work |
| Heavy | $35.78 \pm 0.16^{d}$ | $38.87 \pm 0.41^{a}$ | $37.57 \pm 0.23^{b}$ |
| Moderate | $36.57 \pm 0.13^{c}$ | $37.61 \pm 0.45^{b}$ | $36.62 \pm 0.30^{c}$ |
| Light | $36.49 \pm 0.13^{c}$ | $38.19 \pm 0.39^{a}$ | $37.02 \pm 0.29^{b}$ |
| Control | $35.39 \pm 0.25^{d}$ | $35.78 \pm 0.18^{d}$ | $36.06 \pm 0.18^{c}$ |
| P-value | .000 | .000 | .008 |

abcValues within the same column and rows bearing different superscript vary significantly at P<0.05

### 3.3.2 WATER INTAKE, SWEAT RATE AND URINE EXCRETED

For the out door group, sweat rate was the highest rate with heavy workload, decreased in both light and control groups, while the moderate work load group showed the lowest rate. Water intake increased with heavy work groups and seem to be comparable with other groups as it increased with the increase in sweat rate. As shown by urine specific gravity, only the group with heavy work load showed a clinical status of dehydration (table 3.3.2.1, figure 3.3.2.1.). For indoor conditions, water intake increased with level of workload and was the lowest for the control. No groups showed status of dehydration (3.3.2.2, figure 3.3.2.2).

**Table 3.3.2.1** Out door group, water intake, sweat rate and urine specific gravity with different workloads

| Groups | Water intake (l) | Sweat rate (l/hr) | Urine specific gravity (1.015-1.020) |
|---|---|---|---|
| Heavy | 5.5 | 0.84 | 1.0392 clinical dehydrated |
| Moderate | 2.52 | 0.26 | 0.9550 (well hydrated) |
| Light | 2.66 | 0.37 | 0.9314 (well hydrated) |
| Control | 2.79 | 0.36 | 0.9850 (well hydrated) |

**Table 3.3.2.2.** Indoor groups, water intake, sweat rate and urine specific gravity with different workloads

| Groups | Water intake (l) | Sweat rate (l/hr) | Urine specific gravity (1.015-1.020) |
|---|---|---|---|
| Heavy | 0.76 | 4.82 | 1.00434 (well hydrated) |
| Moderate | 0.64 | 4.17 | 0.99106 (well hydrated) |
| Light | 0.41 | 3.48 | 0.95016 (well hydrated) |
| Control | 0.36 | 2.79 | 0.9850 (well hydrated) |

Specific gravity = < 1.015 means: well hydrated

Specific gravity = 1.015 – 1.020 means: normal hydrated

Specific gravity = 1.020 – 1.025 means: moderate hydrated

Specific gravity = 1.025 – 1.03 means: dehydrated

Specific gravity = >1.03 means: clinical dehydrated

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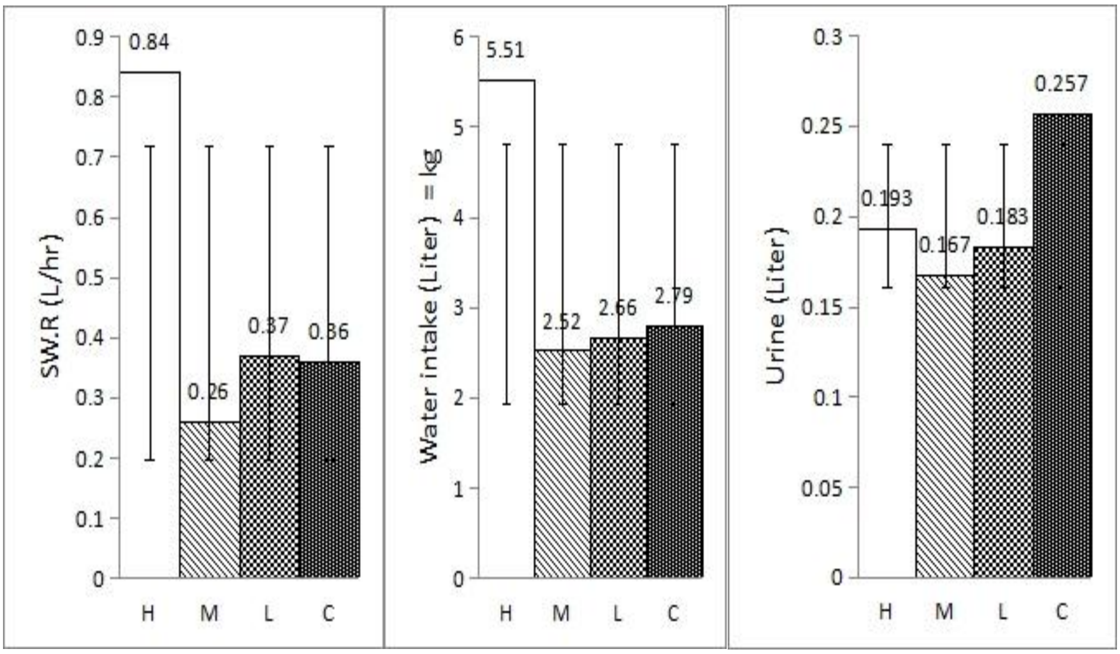
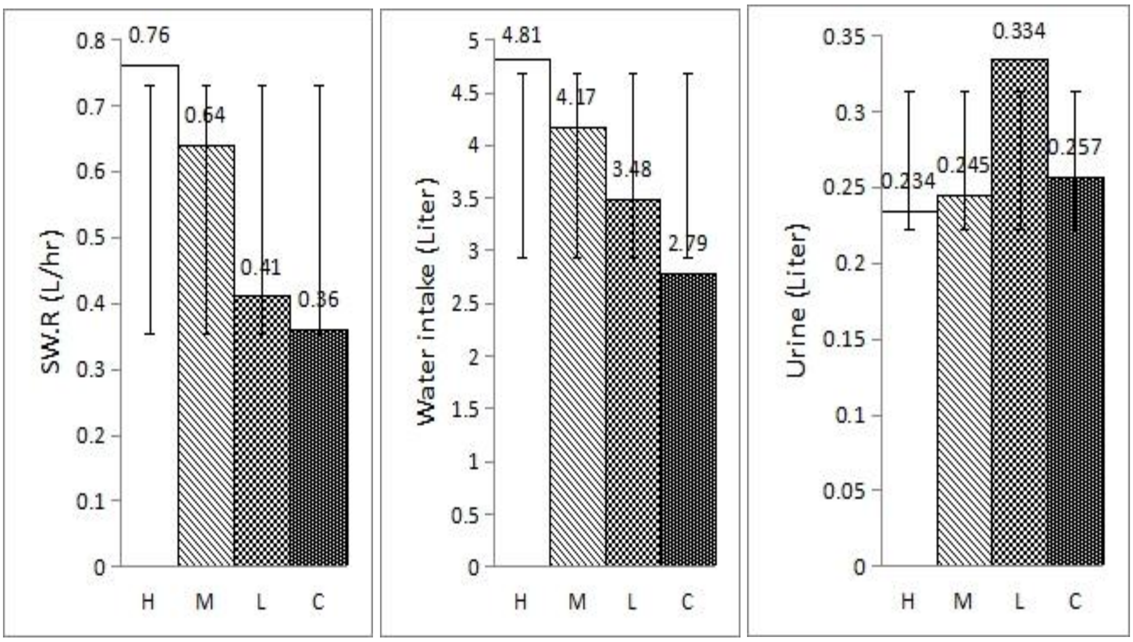
**Fig 3.3.2.1:** Out door groups, sweat rate, water intake and urine excretion with different workloads




H= heavy workload group, M= moderate workload group, L= light workload group, C= control workload group

**Fig 3.3.2.2.** indoor groups, sweat rate, water intake and urine excretion with different workloads




H = heavy workload group, M= moderate workload group, L= light workload group

## 3.3.2.3 PHYSIOLOGICAL STRAIN INDEX (*PSI*)

Physiological heat strain index for outdoor, indoor and control groups (table 3.3.2.3.1.) with different working loads showed that the subjects carrying heavy, moderate and light workloads had significantly ($P < 0.001$) higher PSI than the control group under indoor thermal environment. For the outdoors light and control group, light and heavy or moderate groups did not differ significantly ($P > 0.05$) (table 3.3.2.3.2).

## RELATIONSHIP BETWEEN SWEAT RATE AND (PSI).

As shown by figures for both out door (figure 3.3.2.3.1) and indoor (figure 3.3.2.3.2) conditions for workers carrying different workloads, sweat rated increased with PSI, was the highest for heavy workload decreased gradually with moderate and light workloads reaching the minimum with the control group.

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## CORRELATION REGRESSION BETWEEN SWEAT RATE AND WATER INTAKE

Correlation regression between sweat rate and water intake for outdoors workers showed significant positive (P <0.001) correlation ($y = 0.0662x + 0.117$). For indoors the correlation ($y = 0.1648x - 0.0707$) was also positive and highly significant (0.000).

Correlation regression between specific gravity of urine and water intake showed significant for both outdoors (P <0.05, $y = 0.119x + 2.7767$) (Fig 3.19.1A) and indoors (P <0.001, $y = 5.5638x - 1.277$ ) workers.

## 3.7.2.3 CORRELATION/ REGRESSIONS BETWEEN AIR TEMPERATURE AND PHYSIOLOGICAL HEAT STRAIN INDEX (PSI)

Correlation and regression analyses between air temperature and the Physiological Heat Strain Index (PSI) had shown significant correlations for both outdoor (P <001, y = 0.0083x + 1.1846) and indoors (P <0.001, y = 0.2942x - 7.679).

**Table 3.3.2.3.** Physiological heat strain index (PSI) for outdoor, indoor and control groups with different working loads

| groups | PSI for outdoor workers | PSI indoor for indoor workers |
|---|---|---|
| **H** | 1.87±0.32[b] | 4.53±0.53[b] |
| **M** | 1.86±0.20[b] | 3.01±0.69[b] |
| **L** | 0.74±0.25[ab] | 2.75±0.54[b] |
| **C** | 0.05±0.32[a] | 0.05±0.32[a] |
| **P-value** | .000 | .001 |

[abc]Values within the same column bearing different superscript, significantly at P<0.01 significantly P-Value (P<0.05) levels of group

**Fig 3.3.2.3.1:** Relationship between sweat rate and physiological strain index (PSI) for subjects with different workload under outdoor environment

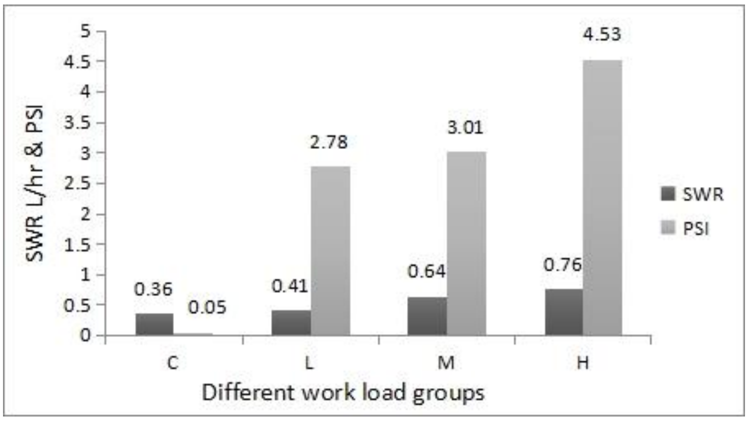
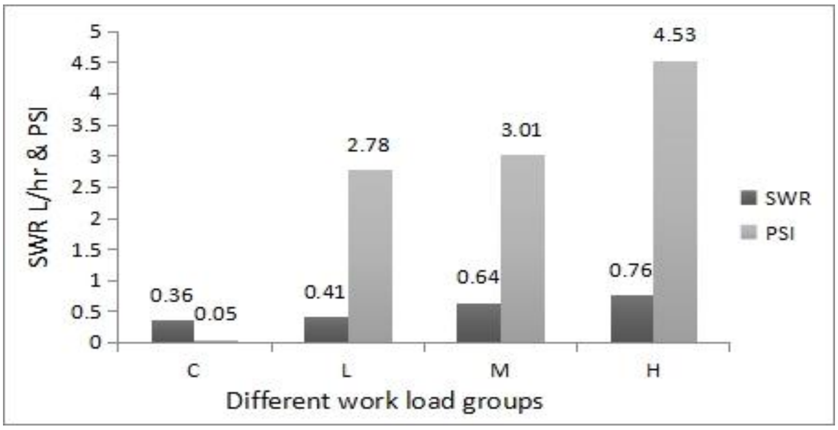



**Fig 3.3.2.3.2** Relationship between sweat rate and physiological strain index (PSI) for subjects with different workload under indoor environment



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## DISCUSSION

Body temperature increased significantly during and after work compared to before work in all groups, it also increased significantly with the increase of workload. This could be related to the effect of severity of exercise. Such thermal conditions are observed in several outdoor jobs and indoor works (Tanaka, 2007). Research has revealed that six major factors, among many others, determine the total thermal stress load of work in a hot environment: ambient air temperature, relative humidity of water vapour in air, air speed, mean radiant temperature, clothing insulation and physical activity level (Iriki and Simon, 2006). In this study for both out and indoor subjects significant positive correlations were obtained between air temperature, humidity and wind velocity with body temperature. Similarly, it has been shown that, heat is a physical hazard that can pose a problem in almost any work place, especially during the warm months (Inaba, and Mirbod, 2005). It was revealed that people carrying heavy outdoor workload in heat radiation from strong sunlight during the hottest season are likely to be most at risk (Kjellstorm, *et al*., 2009). Indoor workplaces are also affected as small workshops and even factories in low and middle income countries seldom provide air cooling systems (Abderrezak and James, 2002).

Evaporation through perspiration is the body's most effective method of cooling under most circumstances, dissipating up to 600 kcal per hour in optimal conditions (James and Glazer, 2005). Body temperature elevations elicit heat loss responses of increased skin blood flow and increased sweat secretion (Rodahl, 2003). In this study sweat rate was higher for workers carrying heavy workload under outdoor and indoor conditions. Outdoor workers with moderate workload showed lower sweat rate compared with light and control. Similar trends were observed for indoor workers for physiological strain. Sweat loss was found to be better related to the heat load than to the resulting physiological strain; nevertheless, its measurement was useful in determining the fluid loss which has to be replaced during the work day. This could also be confirmed by the significant positive correlation regression obtained between sweat rate and water intake for outdoor and indoor workers. Water intake was also found to be positively related to urine specific gravity and state of hydration. It is therefore imperative that workers performing physical work in hot conditions maintain their hydration status in order to maintain health as well as prevent accidents due to associated reduced cognitive capabilities (Bates and Schneider, 2008).

## CONCLUSION

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). Inadequate thermal stress may cause discomfort and adversely affect the performance, safety and harm to health. Occupational exposure to hot environments may have an adverse effect on the performance, health, comfort of the workers. Prolonged heat stress may lead to loss of body fluid (hypohydration), which in itself impairs performance, especially endurance. In addition, prolonged heat strain may impair mental and psychomotor functions, thereby affecting performance (Rodahl, 2003). The need for an adequate index to describe environmental heat stress which provides a reliable and consistent correlation with the induced physiological strain was already acknowledged especially with respect to industrial working conditions there have been efforts made over decades to develop a general comfort equation and respectively a universal heat stress index (Iriki and Simon, 2006).

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