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DETERMINATION OF THE OPTIMUM HEAT STRESS INDEX AT A FOUNDRY

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ABSTRACT

This paper presents a case study to determine the efficiency of the currently used heat stress indices in correlation with wet bulb globe temperature (WBGT) as a permissible index at a foundry plant and to evaluate the extent of the physiological responses such as heart rate and body temperature in correlation with heat stress indices. The field consisted of a foundry plant where a shift work was in operation. The results indicated that wet globe temperature (WGT), corrected effective temperature (CET), and predicted four-hour sweat rate (P_4SR) indices have the best correlation with WBGT index respectively, and P4SR and CET indices correlate well with physiological responses more successfully than WBGT does in hot-dry conditions, CET index gives the best correlation with body temperature while P_4SR is the most accurate with the heart rate.

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INTRODUCTION

The microclimate at a workplace can be classified as either hot-dry or hot-humid. The effects of such various environments on man and the strains produced differ depending on the thermal conditions. In some industries such as foundries, workers can be exposed to severe heat mostly in the form of radiation and the individuals may experience discomfort. Thus the use of indices is required to assess the thermal stress, but hygienists are experiencing considerable difficulties in the application of these indices to predict the level of heat strain resulting from exposure to stressful hot conditions.[4,5,7] The purpose of the present study, therefore, was to make a comprehensive comparison between heat stress indices to determine the most suitable index in order to predict the tolerability of the thermally-stressful condition in the working environment and the safe values of heat strains in relation to the optimum heat stress indices.

Table I. Means and standard deviation of environmental and physiological parameters

	Environmental					Physiological	
Group	WBGT	CET	P_4SR	HSI	WGT	B. T°C	H. R bt/m
UT	27.57 5.62	27.84 4.08	4.40 2.36	92.24 23.95	28.32 4.92	37.27 0.18	76 4.52
Control	21.47 1.78	23.65 1.88	0.84 0.38	88.35 37.96	23.24 1.85	37.18 0.17	71 4.40

Table II. Regression equations for heat stress indices tested

Undertest group				Control group			
Regression equation			C. C*	Regression equation			C. C*
CET = 0.66	WBGT	+ 9.61	0.91	CET = 1.024	WBGT	+ 1.23	0.99
P_4SR = 0.37	WBGT	− 5.85	0.88	P_4SR = 0.18	WBGT	− 3.14	0.87
HSI = 3.13	WBGT	+ 5.94	0.745	HSI = −3.93	WBGT	+ 172.8	−0.18
WGT = 0.87	WBGT	+ 4.34	0.99	WGT = 1.03	WBGT	+ 1.00	0.999

*C. C = Correlation Coefficient

MATERIAL AND METHODS

This study was conducted in Alborz industrial city located in central Iran, one hundred km northwest of Tehran. A foundry plant was chosen as a hot-dry industry. The process was carried out both mechanically and manually in the plant. Scrap iron was used to produce pipes and iron connectors. The scrap iron was molten in four electric induction furnaces (with eight thousand kg capacity each). Three of the furnaces were usually working. Pipes were produced mechanically by a centrifuge system, while other products such as iron connectors were poured manually. There was no ventilation system in the plant.

In this case study, a total of 120 workers operating in hot places as well as 28 guards for power and foundry maintenance as a control group were examined. The subjects were clothed in routine outfit. The sampling sites were selected and environmental parameters including dry wet bulb, natural wet bulb, globe temperature, air velocity, relative humidity, water vapour pressure as well as physiological parameters such as heart rate and body temperature were measured.

All measurements were carried out over three consecutive weeks when a three-shift system was in operation. These shifts covered the following schedules: 6 am- 2pm (day shift), 2-10 pm (afternoon shift) and 10 pm-6 am (night shift). The readings were obtained at the beginning, at maximum activity (during peak hour) and at the end of each shift. Measurements were taken according to recommended guidelines (ISO 7243). The subjects were also checked to see whether they had any physical problems or used any kind of drugs. The results revealed that all subjects were healthy and the work rate was estimated to be moderate type so the metabolism was in the range of 200-350 Kcal-hr.[1]

RESULTS

The average age of the subjects was 33.93± 10 yrs., their average body weight 66.86 ± 9.62 kg, and their average height 171.25 ± 6.28cm. The same data for the control group was 34.7 ± 9.5 yrs., 67.53 ±7.62kg, 171.67 ± 7.49 cm, respectively.

The currently used heat stress indices, WBGT, WGT, CET and heat stress index (HSI) were calculated from environmental data measured during peak hour. Table I summarizes the mean values and standard deviation of physiological and environmental parameters.

Statistical treatment of the data was done to estimate regression equations. These equations are shown in Table II along with the correlation coefficients. The correlation coefficients indicate significant correlation at $P < 0.01$. The results also indicate that the WGT, CET and P_4SR indices have the best correlation with WBGT index, respectively.

The data is also evaluated from a statistical point of

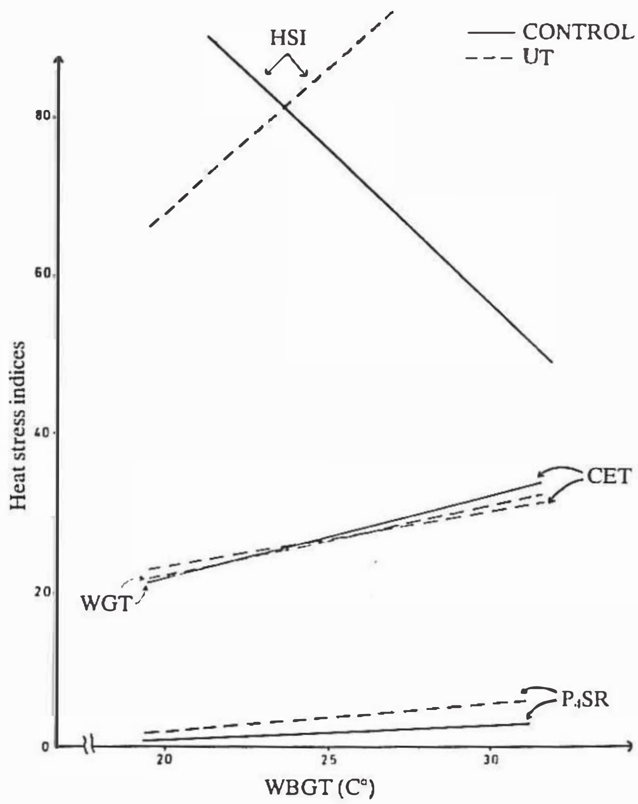

Fig. 1. Regression lines of the Heat Stress Indices Versus WBGT

Table III. Regression equations and correlation coefficients for body temperature and heart rate

UT				Control			
Equation			C. C	Equation			C. C
BT = 0.010	WBGT	+ 36.98	0.322	BT = 0.065	WBGT	+ 35.78	0.671
BT = 0.015	CET	+ 36.86	0.329	BT = 0.065	CET	+ 35.64	0.708
BT = 0.021	P_4SR	+ 37.17	0.275	BT = 0.346	P_4SR	+ 36.88	0.762
BT = 0.026	HSI	+ 34.84	0.012	BT = 1.35×10^{-3}	HSI	+ 37.05	0.297
BT = 0.011	WGT	+ 36.94	0.314	BT = 0.062	WGT	+ 35.74	0.663
HR = 0.299	WBGT	+ 68.08	0.372	HR = 1.286	WBGT	+ 43.20	0.520
HR = 0.475	CET	+ 63.10	0.428	HR = 1.235	CET	+ 41.59	0.527
HR = 0.914	P_4SR	+ 72.32	0.476	HR = 8.288	P_4SR	+63.81	0.713
HR = 0.074	HSI	+ 69.51	0.386	HR = 0.062	HSI	+ 76.32	−0.538
HR = 0.323	WGT	+ 67.18	0.352	HR = 1.211	WGT	+ 42.66	0.508

view to estimate the regression equations of body temperature and heart rate versus heat stress indices. Table III summarizes the regression equations and correlation coefficients calculated from the environmental and physiological studies.

DISCUSSION

Environmental Parameters

Figure 1 shows the regression lines of all heat stress indices versus WBGT for both under test (U. T.) and control groups. The appropriated lines of CET, WGT and P_4SR are almost parallel in both groups, while HSI line for UT are uniquely parrallel to HSI line for control group and it doesn't have any correlation with the others.

Among the above mentioned indices, WGT is calculated from the value of WBGT index and this is the reason for the best correlation of this index with WBGT.[2-4]

HSI depends strongly on air velocity (HSI depends on 1/airvelocity), so its correlation with WBGT is weak (negative C. C. in control group) and it is shown in Fig 1. In the work place although the air velocity is extremely low and there is actually no heat stress, the calculated HSI is very high, for example in control shops during the night shifts. In controlled test rooms, where the air velocity does not change, one can not appreciate the subjection of HSI to air velocity. Nevertheless in this study when the air velocity changes in different shops, the variation of HSI is remarkable. Thus CET and P_4SR indices prove to have the best correlation with WBGT index, in both under test and control groups. Since WBGT is in fact a mathematical expression of the CET index, so this is the reason for the good correlation.

Physiological Parameters

Considering the correlation coefficients in UT and control groups, it was found that the regression equations of HR versus P_4SR have the best correlation coefficients, i. e. the value of CC is more significant than the others. So the angles between the P_4SR line and the other lines were calculated by the following formula: = arc tg $(m - m'/1 + mm')$ where m is the slope of HR line versus P_4SR and m' is the slope of HR versus the four lines. Regarding the angles and regression lines which are drawn in Fig. 2 it can be observed that CET, WGT and WBGT have the best correlation with P_4SR line in UT group respectively, i. e. their lines are parallel with P_4SR line, while HSI is not parallel with the other three lines (WBGT, P_4SR and CET). In the control group we obtain identical results as well. Table IV shows the angles between HR versus P_4SR line with other lines.

If the measured mean values of heat stress indices in Table I were inserted in regression equations, Table IV, the resultant HR values would be 76.3, 76.3 and 76.3 bt/min for UT and 70.8, 70.8, 70.7 bt/min for the control group respectively. Comparing the calculated and measured values, it is estimated that P_4SR has the best correlation with HR in UT group but WBGT is the most favourable one in control group which is contrary to the measured values (P_4SR with C. C= O.713). This may be due to low precision of P_4SR value on the nomogram for the prediction of P_4SR, especially for low ones.

Since the best result in the UT group belongs to the P_4SR, a list of reference values can be obtained for the heart rate with the insertion of the WBGT reference values suggested by ISO 7243 in obtained equation:[1] P_4SR= 0.37 WBGT-5.85. Then the acquired P_4SR

Table IV. Angles between P_4SR and other lines

Group	WBGT	CET	P_4SR	HSI	WGT
U.T	25.7	17	0	38.2	24.5
Control	31	32.1	0	79.6	32.6

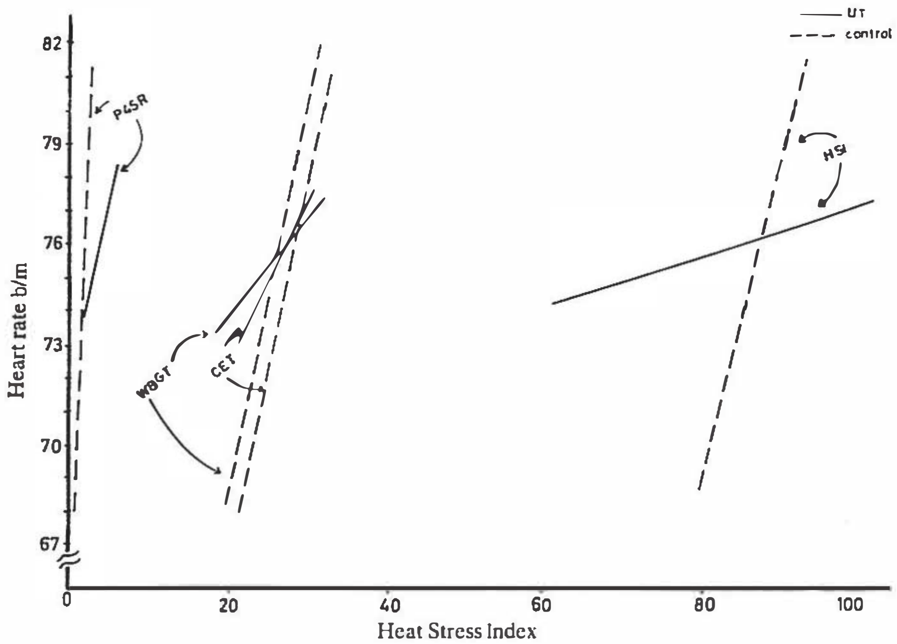

Fig.2: Regression Lines of Heart Rate Versus Heat Stress Indices

reference values are to be inserted in the related heart rate regression equation versus P_4SR. Thus, the HR reference values in regard to the acclimatized worker in different metabolic rates are obtained and summarized in Table V.

The same calculations are carried out to evaluate the correlation between body temperature and heat stress indices (Fig. 3). The regression lines show that CET, P_4SR and WBGT have the better correlation with BT than HSI. Subsequently, the measured mean values of heat stress indices in Table I are inserted in the regression equations of the body temperature. The calculated BT is 37.27°C for UT. It is concluded that our calculations meet favourably with our measurements.

Conclusion

A foundry plant was chosen as a hot-dry industry to study the optimum heat stress index on the basis of the physiological responses. Five heat stress indices were selected to be used in this study. Wet bulb globe temperature (WBGT), predicted four hour sweat rate (P_4SR), heat stress index (HSI), corrected effective temperature (CET), and wet globe temperature (WGT). Heart rate (H.R.) and body temperature (B. T) were measured as physiological parameters simultaneously with heat stress indices. The routine procedure of the experiment was as follows.

— Interviewing each worker before test.
— Determination of the metabolic rate.
— Monitoring the physiological responses.
— Monitoring the environmental parameters.

The regression equations were developed for the physiological parameters versus heat stress indices. An evaluation of the physiological parameters and these indices revealed that heart rate has the best correlation with P_4SR, whereas in regard to the body temperature, CET is preferred.

Table V. Reference Value of Heart Rate

Metabolic Rate Class	Metabolic Rate /M: Related to a unit skin surface area W/m^2	Metabolic Rate /M: Total (for a mean skin surface area of 1.8 m^2) W.	Reference value of HR: Person acclimatised to heat b/m	
Resting	M < 65	M < 177	78	
1	65 < M < 130	117 < M < 234	77	
2	130 < M < 200	234 < M < 360	76.5	
3	200 < M < 260	360 < M < 468	No sensible air movement 75	sensible air movement 76
4	M > 260	M > 468	75	75

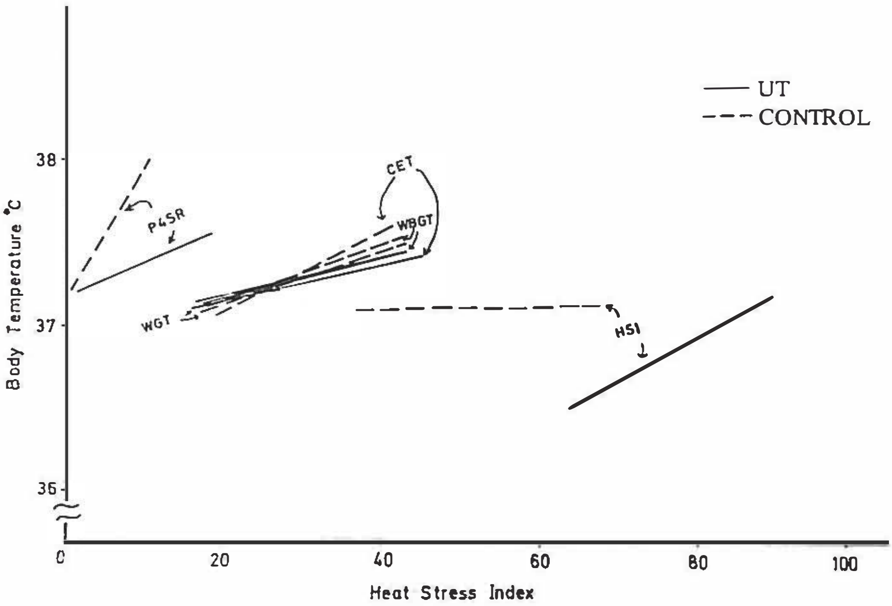

Fig.3: Regression Lines of Body Temperature Versus Heat Stress Indices

Permissible limits for the WBGT published by ISO were used to prepare similar tabulation for the best suited index as well as heart rate.

APPENDIX

Heat stress indices.

The following five stress indices were selected for use in this study:

1. The Wet Bulb Globe Temperature (WBGT) index proposed by Yaglou and Minard. The index number consists of a simple weighing of the globe, natural wet bulb and dry bulb temperature.
2. Wet Globe Temperature (WGT) as proposed by Botsford. The index number is determined by only one thermometer placed in a black globe, covered by wet black cloth.
3. Corrected Effective Temperature (CET) as proposed by Bedford who used the globe temperature plus air velocity. This consists of a corrected form of the effective temperature.
4. Heat Stress Index (H. S. I) which is an analytical index and is described as a percentage of the ratio: E_{req} to E_{max}.
5. The predicted four-hour sweat rate (P_4SR) index developed by Mc Ardle, et al. This is an empirical index predicting total sweat loss during four-hour exposure.

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