Article Title Page

Developing a heat stress model for construction workers

Author Details *(please list these in the order they should appear in the published article)*

Albert P.C Chan
Dept. of Building and Real Estate, Hong Kong Polytechnic University, Hong Kong, China

Michael C.H. Yam
Dept. of Building and Real Estate, Hong Kong Polytechnic University, Hong Kong, China

Joanne W.Y. Chung
Dept. of Health and Physical Education, The Hong Kong Institute of Education, Hong Kong, China

Wen Yi
Dept. of Building and Real Estate, Hong Kong Polytechnic University, Hong Kong, China

NOTE: affiliations should appear as the following: Department (if applicable); Institution; City; State (US only); Country. No further information or detail should be included

Corresponding author: Albert P.C Chan

Corresponding Author's Email: bsachan@inet.polyu.edu.hk

☐ *Please check this box if you do not wish your email address to be published*

Acknowledgments (if applicable):

This project is funded by a grant from the Research Grants Council of the Hong Kong Special Administrative Region, China (RGC Project No. PolyU510409). The support from the Hong Kong Housing Authority, Sun Hung Kai Properties Ltd, Yau Lee Construction Co Ltd, and China State Construction Engineering (HK) Ltd, is deeply appreciated. The research team is also indebted to the technical support from technicians of Hong Kong Polytechnic University and Hong Kong Institute of Education. In particular, the participation of front-line rebar workers in this experimental study is gratefully acknowledged. This paper forms part of the research project titled "Experimental research on health and safety measures for working in hot weather", from which other deliverables will be produced with different objectives/scopes but sharing common background and methodology. The authors also wish to acknowledge the contributions of other team members including Prof Francis Wong, Dr Daniel Chan, Dr Del Wong, Prof Esmond Mok, Dr Geoffrey Shea, Dr Min Wu, Dr Herbert Biggs, Dr Donald Dingsdag, and Miss Alice Guan.

Biographical Details (if applicable):

Prof. Albert Chan is a Chartered Builder, Engineer, Project Manager, and Surveyor by profession. Prof. Chan has worked in a number of tertiary institutions both in Hong Kong and overseas, including City Polytechnic, the predecessor of the City University of Hong Kong, University of South Australia and The Hong Kong Polytechnic University. He was a Senior Lecturer and Deputy Head of the School of Building and Planning at the University of South Australia. Prof. Chan joined the Department of Building and Real Estate in 1996 and is currently an Associate Head, and Chairperson of the Departmental Teaching and Learning Committee. Prof. Chan has been commissioned by a number of organizations to provide consultancy services in project management and construction economics. Some of the major clients include: Department of Labour and Industry of the South Australian Government, Department of Building and Construction of the City University, KCRC, MTRCL, Hong Kong Jockey Club, Hong Kong Housing Authority, and the Environment, Transport and Works Bureau of the HKSAR Government. He has produced over 500 publications in refereed journal papers, international refereed conference papers, consultancy reports, and other written outputs. He

has won a number of prestigious research paper and innovation awards such as the 1995 Fred Wilson Memorial Prize, the Year 2000 Best Safety Paper Gold Prize Award, a Commemorative Medal in the CIOB 2001 Research Papers Competition, The CIOB Innovation Achievers Award for 2008/09, Gold Medal with the Congratulations of the Jury in Geneva, 2008, and the Award of High Scientific and Technological Level of the Invention, 2008. Prof. Chan holds an MSc in Construction Management and Economics at the University of Aston in Birmingham, and a PhD in Project Management at the University of South Australia. Prof. Chan maintains good links with overseas institutions. He has been an Adjunct Professor of the Queensland University of Technology, the University of South Australia, and the Bond University in Australia; and the Huaqiao University of the PRC. Prof. Chan was also a Founding Director of Construction Industry Institute, Hong Kong, which was a joint research institution developed by the industry and the academia.

Dr. Michael Yam obtained his BSc. in Civil Engineering with Distinction and MSc. at the University of Alberta, Canada and completed his PhD degree at the same University in 1994. He subsequently was appointed as a research engineer at the University before returning to Asia in 1995. Prior to joining the Department of Building and Real Estate in early 2002, Michael has spent several years with the University of Macau as Assistant Professor of Civil Engineering, as well as the Hong Kong Technical College as Lecturer. He has also obtained consultancy experience in the areas of the design and construction of both reinforced concrete buildings and structural steelworks in Hong Kong. Michael is a member of the Hong Kong Institution of Engineers, Institution of Professional Engineers New Zealand, Institution of Engineers, Australia and the American Society of Civil Engineers.

Professor Joanne Chung is currently the Chair Professor of Health Studies and the Head of Department of Health and Physical Education of the Institute. She is also the Co-Principal Investigator of the Centre for Integrative Digital Health Centre of The Hong Kong Polytechnic University. Her creativity, leadership and perseverance in research activities in the emerging and potentially lucrative field of digital health and study of pain are especially noteworthy, having resulted winning of many international prizes in the past years and has published extensively. She is a pain specialist in both research and clinical practice. She has researched and developed an integrative pain management protocol for patients afflicted with cancer, chronic or idiopathic pain. Prof. Chung has also devoted her effort in developing school health. Old habits die hard. Good healthy habits and lifestyles have to start young. Her ambition is to instill health concepts into our young children as they are the masters of our future society. Good health education and practice will not just cut health financing cost but also give this place a vibrant and joyful society.

Miss. W. YI, BEng, MPhil, completed her MPhil at Faculty of Construction Management and Real Estate, Chongqing University. She is currently a research assistant for the heat stress project at the Department of Building and Real Estate, The Hong Kong Polytechnic University

Structured Abstract:

Purpose - Heat stress, having caused preventable and lamentable deaths, is hazardous to construction workers in the hot and humid summers of Hong Kong. The purpose of this article is to develop a heat stress model, based on the Wet Bulb Globe Temperature (WBGT) index.

Design/methodology/approach - Field studies were conducted during the summer time in Hong Kong (July to September 2010). Based upon 281 sets of synchronized meteorological and physiological data collected from construction workers in four different construction sites between July and September 2010, physiological, work–related, environmental and personal parameters were measured to construct and verify the heat stress model.

Findings - It is found that drinking habit, age and work duration are the top three significant predictors to determine construction workers' physiological responses. Other predictors include percentage of body fat, resting heart rate, air pollution index, WBGT, smoking habit, energy consumption, and respiratory exchange rate. The accuracy of the model is verified against data which has not been used in developing the model. The accuracy of the heat stress model is found to be statistically acceptable (Mean Absolute Percentage Error = 5.6%, Theil's U inequality coefficients = 0.003).

Practical implications - Based on these findings, appropriate work-rest pattern can be designed to safeguard the well being of workers when working in a hot and humid environment.

Originality/value - The model reported in this paper provides a more scientific and reliable prediction of the reality which may benefit the industry to produce solid guidelines for working in hot weather.

Keywords Heat stress model, Rebar work, Wet Bulb Globe Temperature (WBGT)

Paper Type Research paper

For internal production use only

Running Heads:

Developing a heat stress model for construction workers

Abstract

Purpose - Heat stress, having caused preventable and lamentable deaths, is hazardous to construction workers in the hot and humid summers of Hong Kong. The purpose of this article is to develop a heat stress model, based on the Wet Bulb Globe Temperature (WBGT) index.

Design/methodology/approach - Field studies were conducted during the summer time in Hong Kong (July to September 2010). Based upon 281 sets of synchronized meteorological and physiological data collected from construction workers in four different construction sites between July and September 2010, physiological, work–related, environmental and personal parameters were measured to construct and verify the heat stress model.

Findings - It is found that drinking habit, age and work duration are the top three significant predictors to determine construction workers' physiological responses. Other predictors include percentage of body fat, resting heart rate, air pollution index, WBGT, smoking habit, energy consumption, and respiratory exchange rate. The accuracy of the model is verified against data which has not been used in developing the model. The accuracy of the heat stress model is found to be statistically acceptable (Mean Absolute Percentage Error = 5.6%, Theil's U inequality coefficients = 0.003).

Practical implications - Based on these findings, appropriate work-rest pattern can be designed to safeguard the well being of workers when working in a hot and humid environment.

Originality/value - The model reported in this paper provides a more scientific and reliable prediction of the reality which may benefit the industry to produce solid guidelines for working in hot weather.

Keywords Heat stress model, Rebar work, Wet Bulb Globe Temperature (WBGT)

Paper Type Research paper

1. Introduction

The existence of extreme hot conditions in many work environments may have a serious negative effect on the health and safety of employees (Fogleman et al, 2005). Such extreme conditions are commonly encountered in many occupational settings such as steel and iron manufacturing, glass factories, mining, textiles, ceramics, food canneries, and outdoor operations (Kähkönen et al, 1992). The construction industry involves many of these occupational settings and is found to be more susceptible to heat stress than other industries (JCOSH, 2001). Construction workers are subjected to heat stress not only from outdoor physical work but also in confined spaces which could be even worse. In Hong Kong, the incidence of heat stress in the construction industry has been alarming and caused a number of verifiable reported deaths which suggest that heat stress was the probable causal factor (Apply Daily, 2007-2010). These incidents have drawn the attention of the government, statutory bodies and the industry to investigate the health and safety problem of working in hot weather. The Construction Industry Council (CIC), which is a statutory coordinating body encompassing all key sectors in the construction industry of Hong Kong, has set up a Task Force on Working in Hot Weather and has promulgated a set of guidelines on preventing heat stress. Although the literature abounds with general guidance notes on heat stress hazards in construction (Labour Department, 2004; Construction Industry Council, 2008; US Department of Labor, 2004; ISO7243; Department of Health, 2010), there is a lack of scientific research specific to the construction industry to put forward safety measures for combating heat stress based on reliable clinical parameters.

2. The original heat stress model

Rebar work is one of the most labor-intensive and long duration tasks in construction (Balasubramanian and Prasad, 2007; Jarkas, 2010). Unfortunately, it was reported that 10 percent of rebar workers in Hong Kong have suffered heat stroke (Apple Daily, 2009) and a rebar worker was reported to fall to death on a construction site in last summer because of heat stroke (Apple Daily, 2010). Hence, heat stress can seriously threaten rebar workers' health and safety. To ensure the health and safety of site personnel working in hot weather, research on physiological responses of rebar workers under heat stress is urgently needed.

For this purpose, the authors have developed a heat stress model based on a relatively simple thermal indicator, Heat Index (HI), which is a function of temperature and relative humidity, to determine how a worker's physiological responses change with the environmental parameters and other factors (Chan et al, 2011). Based upon 281 sets of synchronized meteorological and physiological data collected from bar benders and fixers in four different construction sites between July and September 2010, physiological, work–related, environmental and personal parameters were measured to construct a heat stress model with an adjusted R^2 of 0.78 ($p<0.05$), which is shown as Eq. (1) (Chan et al, 2011). Human physiological responses were proxy by the Rating of Perceived Exertion (RPE), which is defined as the intensity of subjective effort, stress, or discomfort felt during physical activity (Foster et al, 2001). The model reported that many factors would affect human physiological responses. These include physiological factors such as heart rate, ventilation, respiratory rate, oxygen uptake and fatigue in undertaking the work activity; work-related factors such as type of exercise and time; environmental factors such as air quality, temperature, and relative humidity; as well as other personal factors such as age, percentage of body fat, and drinking/smoking habits (Chan et al, 2011).

$$\mathrm{RPE} = -7.27+0.11HI+1.26T+0.09API+0.08A-0.05PBF+2.23DH+0.38SH+0.17EC+0.17RER \qquad (1)$$

where *HI* is heat index (^{o}C); *T* is work duration (hour); *API* is air pollution index; *A* is age; *PBF* is percentage of body fat (%), *DH* is drinking habit (“none”= 0, “occasionally”= 1, “usually”= 2), *SH* is smoking habit (“none”= 0, “occasionally”= 1, “usually”= 2); *EC* is energy consumption; and *RER* is respiratory exchange rate.

3. Limitations of the original model

Although the prediction percentage error of the original model is statistically acceptable, the model has been criticized of utilizing a relatively simple indicator, HI, to measure the thermal environment. HI is a rough indicator (a function of temperature and relative humidity) and does not fully reflect heat stress on human body in terms of environmental parameter. The National Weather Service (NWS) heat index (HI) was derived from a database generated by a more complex mathematical model developed by Steadman (1979). Simplifying a complex, multi-input model into a single equation using two common meteorological values (temperature and humidity) may oversimplify the real environmental condition. When conditions differ significantly from the standard conditions, such as a higher or lower solar load or wind speed, the actual risk may also vary significantly from the level predicted using the standard inputs. Sunlight is the main component of the environmental heat load (Brotherhood, 1987), and adequate air movement is essential for the efficient evaporation of sweat (Brotherhood, 2008). By ignoring sunlight and wind, the temperature-humidity limits could underestimate or overestimate environmental warmth. The original heat stress model, using air temperature and relative humidity to evaluate HI, does not fully reflect the complex thermal environment-physiological relationship.

A wet-bulb globe temperature index (WBGT) was invented more than 50 years ago and is now the most widely used index in assessing heat stress. It was invented and first used during the 1950s as one element in an imaginative and successful campaign to control heat illness in training camps of the United States Army and Marine Corps (Yaglou and Minard, 1957). The equation to evaluate the WBGT in outdoor condition is shown in Eq. (2). And its main strengths are that it accounts for the effects of sun and wind – the two crucial components of the outdoor climate - as well as to the air temperature and humidity (American College of Sports Medicine, 1996; Sports Medicine Australia, 2006; Budd, 2008).

$$\mathrm{WBGT} = 0.7T_w + 0.2T_g + 0.1T_d \tag{2}$$

where

T_w = Natural wet-bulb temperature (humidity indicator); T_g = Globe thermometer temperature (measured with a globe thermometer, also known as a black globe thermometer, to measure solar radiation); T_d = Dry-bulb temperature (normal air temperature).

This index has also been recognized by other organizations for setting limits in industrial plants (National Institute for Occupational Safety and Health, 1986), approved by the ISO organization as an international standard for heat load assessment (ISO, 1989) and as a safety index for workers in different occupations (Chaurel et al. 1993; Froom et al. 1992; Gun and Budd, 1995; Singh et al. 1995).

Furthermore, the original model simply utilized percentage of body fat (PBF) to reflect an individual's fitness level. It is believed that resting heart rate (RHR) also has a great effect on the worker's sensation of the thermal environment. Indeed, previous studies demonstrated that elevated resting heart rate (RHR) was a predictive factor for morbidity and mortality

(Kannel et al, 1987). As a significant determinant in the development and progression of physical illness, RHR independently predicted myocardial infarction and coronary deaths (Kannel et al. 1996). Thus, RHR is also included as a contributing factor of personal physique as well as PBF in developing the enhanced model.

From the above, it could be argued that there is a need for developing a more embracing heat stress model which could capture all input variables that have an impact on physiological response. This should lead to a more accurate estimate of the change in rebar workers' physiological condition due to thermal environment variations. Therefore WBGT is adopted in this study to refine the original model and to develop an enhanced heat stress model.

4. Method of data collection

Field studies were conducted during the summer time in Hong Kong (July to September 2010). The study was conducted according to the Declaration of Helsinki and the protocol was fully approved by the Human Subjects Ethics Application Review System (HSEARS) of authors' employing institution before the commencement of the assessments (The Hong Kong Polytechnic University, 2008). The participants were informed of the purpose and the procedure of the study. Their participation was on a voluntary basis and the participants can withdraw any time as they desired. Prior to the experiment, the participants were asked to rest at room temperature of approximately 22°C for 15 minutes to stabilize their body temperature and heart rates. During this period, they were asked to complete a pre-experiment data collection sheet which includes questions on age, smoking, drinking habits and other personal information. Then, body weight, percentage of body fat (PBF) (InBody 230, Biospace Co., Ltd.), and heart rate (Heart rate monitor, Polar, Finland) of the participants were measured. Blood pressure (HEM-712C, OMRON, Japan) was measured before the field study (after the 15min RHR measurement) and after the participants cooled down from work for 20 minutes. The minimum heart rate recorded during this period is considered as the resting heart rate (RHR).

During the experiment, the participants performed rebar bending and fixing tasks as per their usual daily work routine and were allowed to drink water as and when they desired. Physiological parameters were measured by a portable metabolic cart (K4b2, COSMED, Rome, Italy). Calibration of gas and volume were carried out prior to recording the measurement of each participant. The metabolic cart allows real-time collection of physiological data. Oxygen consumption (VO2), minute ventilation (MV), respiratory exchange ratio (RER), metabolic equivalent (MET), energy expenditure (EE), heart rate and a train of physiological parameters would be continuously monitored and recorded during the test via a telemetry system (K4b2, COSMED, Rome, Italy) for every 5 seconds. Without disturbing the participants' normal operation, the participants were asked to report a RPE value for every 5 minutes, to indicate the amount of strain or level of exhaustion. Perceived exertion was assessed with Borg CR10 Scale, a 10-point single-item scale with anchors ranging from 1 'very very easy' to 10 'maximal exertion' (Borg, 1990). RPE has been used in evaluating different physical tasks with proven validity and reliability (McDermott et al, 2008). At the same time, a heat stress monitor (QUESTemp°36, Australian) was used to measure and record the prevailing environmental data. The heat stress monitor measures four environmental parameters simultaneously at 1 minute interval: ambient or dry bulb temperature, natural wet bulb temperature, globe temperature, relative humidity from which the corresponding WBGT index can be computed. The recorded WBGT ranged from 26.7 ^{o}C to 36.4 ^{o}C with an average value of 30.6 ^{o}C. Figure 1 shows the set up of the field experiments.

Fig.1 Set up of field experiment

Different stages of construction from foundation works to core structural works were studied to capture a wide spectrum of empirical data. Locations where the participants worked were recorded to ascertain the effects of heat stress under shade and under direct sunlight.

5. Result

5.1 Demographic data

Data were collected for 10 worker-days at four different construction sites in Hong Kong. 12 rebar workers aged between 20 and 60 years were invited to participate. And ten apparently healthy participants without a history of diagnosed major health problem including diabetes, hypertension, cardiovascular disease and neurological problem; and no regular medication intake participated in this study. Two workers did not meet the pre-qualification criteria and were excluded from the experiment. Table 1 shows demographic data of the participants. Participants with a wide spectrum of age, height, body weight, and fitness participated in these studies ensuring a representative sample of rebar workers working in the industry (ACSM, 2008).

Table 1 Demographic data of the participating rebar workers (N=10)

	Mean SD	Range
Age (year)	39.0 ± 12.5	20-55
Height (cm)	169.2 ± 6.5	160-180
Body weight (kg)	60.3 ± 6.2	53.8-74
Percentage of body fat (%)	12.3 ± 6.3	3-23
Resting heart rate (bpm)	82.7 ± 11.9	63-102
Lower blood pressure (mmHg)	80.0 ± 10.0	58-99
Upper blood pressure (mmHg)	127.8 ± 10.8	98-145

Fig.2 shows the job nature of the participating rebar workers, 70% of them were engaged in rebar fixing, while the others undertook bending tasks. Fig.3 manifests the smoking and drinking habits of the participants. Fig.4 indicates the distribution of 10 participants from 4 different construction sites.

Fig. 2 Job nature of the participating rebar workers (N=10)

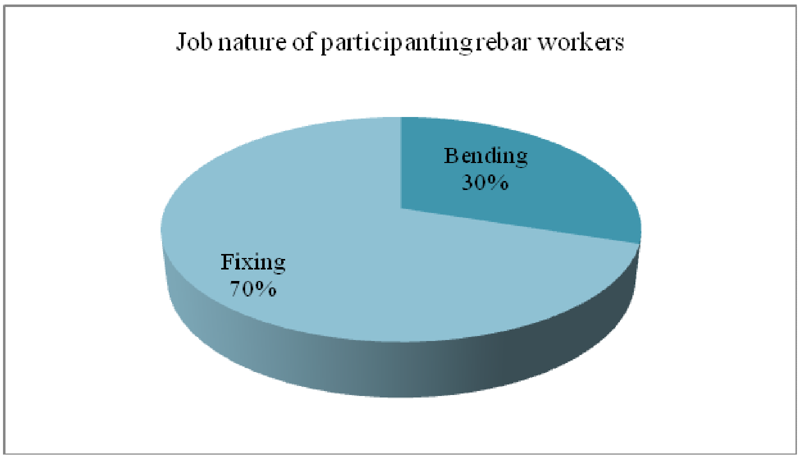
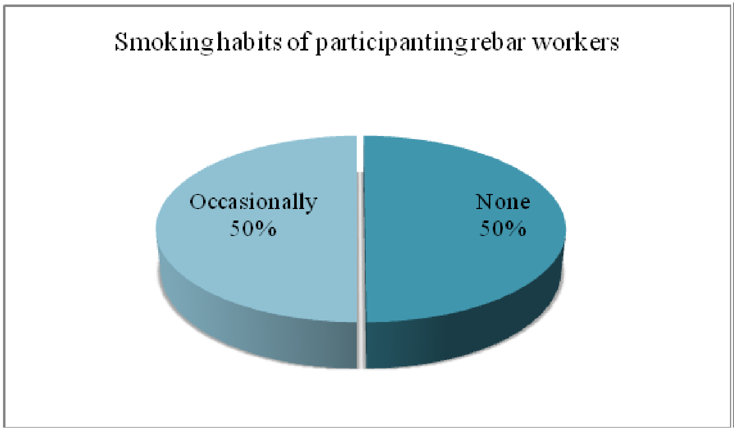


Fig.3 Smoking and Drinking habits of the participating rebar workers (N=10)



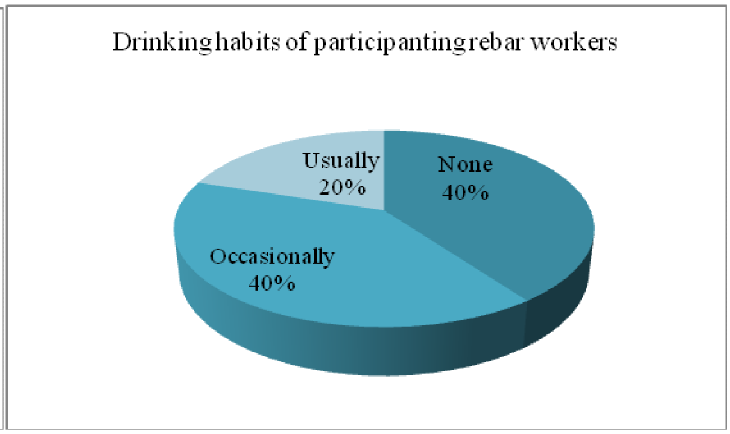
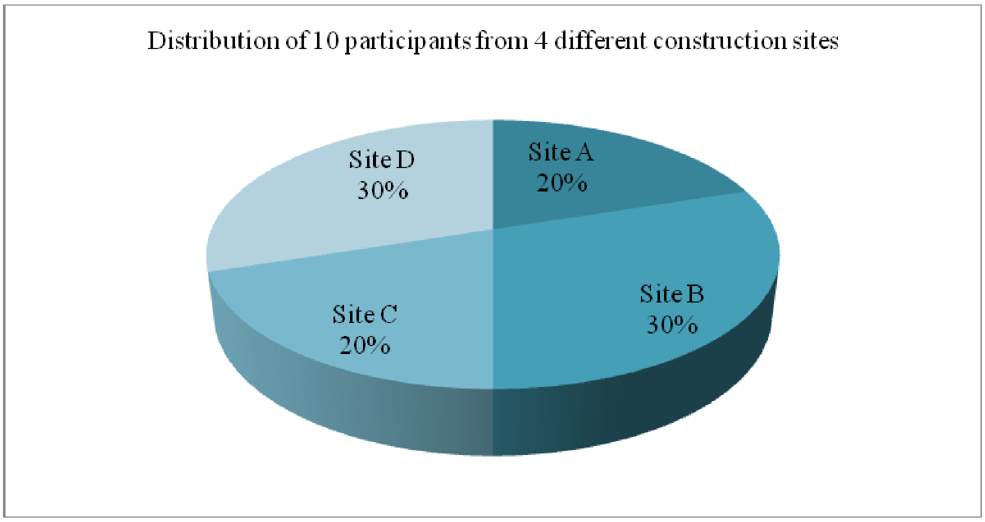


Fig.4 Distribution of 10 participants from 4 different construction sites (N=10)



5.2 Environmental conditions

The environmental conditions (WBGT and API) were captured by a heat stress monitor and by referring to the record broadcasted by the Environmental Protection Department respectively. The heat stress monitor measures four environmental parameters simultaneously at 1 minute interval: ambient or dry bulb temperature, natural wet bulb temperature, globe temperature, relative humidity from which the corresponding WBGT index can be computed. The API, based on the level of 6 atmospheric pollutants, namely sulfur dioxide (SO_2), nitrogen dioxide (NO_2), suspended particulates, carbon monoxide (CO), ozone (O_3), lead (P_b), is measured and broadcasted hourly by the Environmental Protection Department (Environmental Protection Department, Hong Kong, 2007). Table 3 shows a summary of the environmental conditions whilst the field studies were undertaken.

Table 2 Environmental conditions whilst the field studies were undertaken

	Mean SD	Range
T_w (°C)	28.5 ± 2.0	25.3-34.0
T_g (°C)	38.7 ± 2.2	29.8-56.1
T_d (°C)	30.7 ± 6.2	26.2-37.2
H.R. (%)	65.6 ± 14.3	38.0-95.0

WBGT (°C)	30.6 ± 2.2	27.1-36.4
API	30.7 ± 5.9	21-33

Where (T_w) = natural wet-bulb temperature, (T_g) = globe thermometer temperature, (T_d) = dry-bulb temperature, (W) = wind speed in meter per second (m/s), *(H.R.)* = percentage of relative humidity, *(WBGT)* = Wet bulb globe temperature index, and *(API)* = air pollution index

5.3 Physiological measurements

Objective physiological parameters such as oxygen consumption (VO2), minute ventilation (MV), respiratory exchange ratio (RER), metabolic equivalent (MET), energy expenditure (EE), heart rate were monitored every 5 seconds, while subjective physiological parameter RPE was recorded every 5 minutes during the experiment. Table 3 shows the summary results of the physiological measurements. Ultimately 281 data sets of environmental and physiological data together with the corresponding RPEs were captured in four construction sites over ten different working days. 271 sets of data were used to construct the heat stress model, and the remaining 10 sets were used for validation.

Table 3 Physiological measurements of the participating rebar workers (N=10) during the test

	Mean SD	Range
VO_2 (ml/min/Kg)	13.5 ± 4.9	3.17-30.8
MV (l/min)	28.5 ± 8.6	10.1-74.5
RER	1.0 ± 0.2	0.58-1.83
HR (bpm)	115.1 ± 18.1	74.0-162.6
MET (W/m^2)	3.8 ± 1.4	0.9-8.8
EE (Kcal/min)	4.1 ± 1.4	1.0-9.5
RPE	4.7 ± 1.5	2-8

Where *(VO2)* = oxygen consumption, *(MV)* = minute ventilation, *(RER)* = respiratory exchange ratio, *(HR)* = heart rate, *(MET)* = metabolic equivalent, *(EE)* = energy expenditure, *(RPE)* = rating of perceived exertion.

6. Developing an enhanced heat stress model

In this study, factor analysis and multiple regression analysis were two essential tools used for analyzing the meteorological and physiological data and thus formulating a model for predicting the worker's physiological response. The basic assumption of factor analysis is that underlying dimensions or factors can be used to explain complex phenomena (Norusis, 2008). Multiple regression analysis is used to indicate the relative effects of independent variables on a dependent variable and the strength of relationships between the variables (Fellows and Liu, 1997). Both factor analysis and multiple regression analysis were chosen as the statistical tools for developing the enhanced model.

6.1 Factor analysis on physiological parameters

Factor analysis technique was used to identify the underlying cluster of physiological variables on rebar workers. To obtain principal factors for a clearer image, factor extraction with Varimax Rotation and Kaiser Normalization was conducted through the SPSS FACTOR program (SPSS v13.0, USA). The appropriateness of the factor model was evaluated before using factor analysis in this study. The Kaiser–Meyer–Olkin test (KMO) is a measure of sampling adequacy that compares the magnitudes of the partial correlation coefficients. Kaiser (1974) recommended KMO values of greater than the threshold of 0.5 as acceptable and the KMO value obtained in the research is 0.803, which is of meritorious nature and is well above the acceptable threshold (Norusis, 2008). Moreover, the factor extraction process should be terminated when a threshold for maximum variance extracted (e.g., 75–80%) has been achieved. Two underlying grouped factors were extracted in this case, totally accounted for 82% of the variance in responses. Fig.5 shows a plot of total variance associated with each underlying grouped factor. The plot indicates a distinct break between the steep slope of the large individual factors and the gradual trailing off of the rest. This gradual trailing off is referred to as the "scree" as it resembles the rubble that forms at the foot of a mountain (Norusis 2008). SPSS drops the individual factors "3" to "6" as their eigenvalues are less than 1.0. This represents that they are less influential than the two observed underlying grouped factors. The original physiological parameters were all included in one of two underlying grouped factors.

To identify the factors, it is necessary to group the variables that have large loadings for the same factors (Kim and Mueller, 1978). Factor analysis does not attach labels to the factors and the substantive meaning given to a factor is typically based on the examination of what the high loading variables measure (Black, 1997). Corresponding to the weight of rotated components, Energy Consumption (EC) and Respiratory Exchange Rate (RER) were labeled and considered as the two underlying factors.

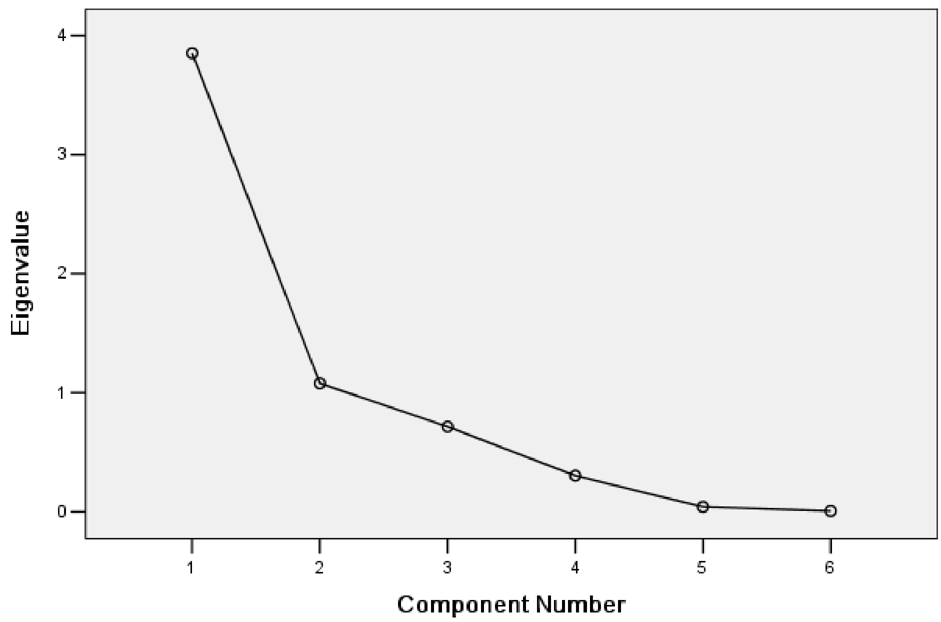


Fig. 5 Scree plot of physiological variables

6.2 Multiple regression analysis

To determine the relationships between the variables, multiple regression analysis is considered as the most widely used statistical procedure (Montgomery et al. 2001). Multiple regression analysis was used to analyze the relationship between a single dependent variable (RPE) and several identified independent variables [e.g. Age (A), Duration (T), Wet Bulb Globe Temperature (WBGT), Air Pollution Index (API), Drinking Habit (DH), Smoking Habit (SH), Percentage of Body Fat (PBF), Resting Heart Rate (RHR), Energy Consumption (EC), Respiratory Exchange Rate (RER), and Job Nature (JN)] (Chan et al. 2011).

Consequently, a stepwise selection method with a significance level of 5% was used to select statistically significant variables to be incorporated into the model. Data variables were added and deleted one at a time and the regression model was rerun, noting at each step the changes in the coefficient of determination (R^2) value and in essence the significance level of variables. De Vaus (1996) stated that the term (R^2) indicates how much variation in the dependent variable is explained by a group of independent variables; and the higher its value, the more powerful the model. Only those variables with a significance level (p-value) of less than 5% were retained for inclusion in the final regression model equations. Since R^2 can be made larger simply by adding more predictor variables to the model, a modification of R^2 - adjusted R^2 has been proposed. Adjusted coefficient of determination (adjusted R^2) does not automatically increase when new predictor variables are added to the model (Glantz and Slinker, 1990), which is particularly useful in the feature selection stage of model building. Accordingly, adjusted R^2 is calculated to reflect the goodness of fit of the model.

However, it is inevitable that physical apparatus for taking measurements may have suffered a transient malfunction, which may result in a large negative impact on the accuracy and reliability of the model; therefore outliers at group-level per condition were identified and removed by SPSS box-plot procedure. Twenty four outliers with two standard deviations and more from the mean were deleted after such analysis.

7. Presentation of regression results

Relationships between RPE and factors of physiological status were established by using the stepwise addition and deletion regression technique. The results of regressions on the single dependent variable RPE and the eleven independent variables are presented in Table 4. A multiple regression equation (RPE) with ten determining factors was finally constructed as shown in Eq. (3). The results from the best-fit run of multiple regression analysis indicated a p-value of less than 0.05 and adjusted R^2 values of 0.79, which implied a good-fit and a robust model.

$$\mathrm{RPE}=-5.43+0.11\,WBGT+1.40\,T+0.10\,API+0.06\,A-0.07\,PBF+2.28\,DH+0.50\,SH+0.14\,EC+0.16\,RER-0.01\,RHR \qquad (3)$$

where *WBGT* is wet bulb globe temperature(^{o}C); *T* is work duration (hour); *API* is air pollution index; *A* is age; *PBF* is percentage of body fat (%); *RHR* is resting heart rate; *DH* is drinking habit ("none"= 0, "occasionally"= 1, "usually"= 2), *SH* is smoking habit ("none"= 0, "occasionally"= 1, "usually"= 2); *EC* is energy consumption; and *RER* is respiratory exchange rate.

Table 4 Multiple Regression Analysis for RPE

Model	Unstandardized Coefficients	Standardized Coefficients (Rank)	t	Sig.
(Constant)	-5.43		-5.86	.000
Drinking habit (*DH*)	2.28	0.60 (1)	15.34	.000
Age (*A*)	0.06	0.53 (2)	12.22	.000
Duration (*T*)	1.40	0.45 (3)	14.08	.000
Air pollution index (*API*)	0.10	0.41 (4)	8.03	.000
Percentage of body fat (*PBI*)	-0.07	-0.31 (5)	-8.86	.000
Smoking habit (*SH*)	0.50	0.26 (6)	7.60	.000
WBGT	0.11	0.15 (7)	4.49	.000
Respiratory exchange rate (RER)	0.16	0.10 (8)	2.95	.003
Resting heart rate	-0.01	-0.10 (9)	-2.88	.004
Energy consumption (*EC*)	0.14	0.09 (10)	3.01	.003

8. Model validation

The validity of the final model is usually assessed in terms of predictive accuracy (Wittink, 1988). That is, the predicted values are compared with the actual observed values to verify the predictive efficacy of the developed model. The heat stress model was validated against data collected under the same experimental procedure. These virgin data sets have not been used in developing the model. Table 5 summarizes ten sets of comparison between actual observed values obtained from the field studies and the predicted values computed from the model. Two relative measures of accuracy dealing with percentage errors were used to compare the forecasting performance of the model.

The Mean Absolute Percentage Error (MAPE) and Theil's U inequality coefficients were used to quantitatively measure how close the forecasted values track the actual data. The prediction percentage error of RPE model is consistently within the acceptable limit of 10%, giving a relatively low MAPE 5.6%. The Theil's U statistics also reveal that the developed RPE model has a high predictability. Hence, the results of the evaluation of forecasted values verify that the RPE model is adequately efficient and robust to predict the physiological responses of rebar workers in Hong Kong.

Table 5 Evaluation of accuracy of the heat stress model by MAPE

Sample	RPE												
	WBGT	T	API	AGE	PBF	DH	SM	EC	RER	RHR	Actual value	Forecast value	Percentage error (%)
1	25.7	0.43	32	42	13.4	1	0	1.27	-0.72	71.4	4	4.35	8.74
2	30.1	0.50	32	42	13.4	1	0	-0.94	-0.18	71.4	5	4.67	6.50
3	32.1	0.54	32	42	13.4	1	0	-0.90	-0.03	71.4	5	4.96	0.87
4	29	0.48	32	42	13.4	1	0	-0.82	-1.55	71.4	5	4.34	13.23
5	31.4	0.52	32	42	13.4	1	0	-0.18	-0.77	71.4	5	4.85	2.90
6	29.8	0.50	32	42	13.4	1	0	-0.80	0.42	71.4	5	4.75	4.97
7	32.2	0.54	32	42	13.4	1	0	0.04	0.41	71.4	5	5.17	3.46
8	30	0.5	32	42	13.4	1	0	2.17	0.13	71.4	5	5.16	3.12

9	28.3	0.47	32	42	13.4	1	0	0.50	1.32	71.4	5	4.89	2.22
10	28.3	0.47	32	42	13.4	1	0	0.25	-0.91	71.4	5	4.50	9.93
													MAPE =5.60%
													U = 0.003

Note: MAPE is mean average percentage error; U is Theil's U statistics.

9. Discussion of the model

An enhanced model, based on Wet Bulb Globe Temperature (WBGT) index, is developed. Comparing with the original model, its main strengths are that (1) WBGT is a thermal indicator integrating four main environmental variables of temperature, humidity, wind speed (wind chill) and solar radiation, which is more comprehensive than the Heat Index (HI) adopted in the original model; (2) an additional variable – resting heart rate (RHR) is included in the regression equation.; and (3) though the adjusted R^2 (0.79) is marginally higher than the original model (0.78), the MAPE (5.6%) is noticeably lower than the original model (7.8%) and hence indicating that the prediction performance of the enhanced model is more reliable and accurate. The newly established model reveals that RPE increases with age, work duration, WBGT, air pollution index, drinking habit, smoking habit, respiratory exchange rate, and energy consumption, but decreases with percentage of body fat and resting heart rate.

The relative importance of factors in predicting RPE can be seen in Table 5. Standardization of the coefficient is usually done to answer the question of which of the independent variables have a greater effect on the dependent variable in a multiple regression analysis, when the variables are measured in different units of measurement (Schroeder et al, 1986). Drinking habit, age, and work duration are the top three predictors to determine rebar workers' physiological responses with drinking habit being the most important factor in predicting rebar workers' physiological response.

10. Conclusions

This study was motivated by the need for refining the initial guidelines on working in hot weather. The original heat stress model was considered as inadequate because it utilized an overly simplified Heat Index (HI) which is a mere function of temperature and relative humidity to measure the thermal environment. The original model failed to express the relationship between physiological response and other key components of environmental variables, namely, radiation and air movement. WBGT is a more widely used index of thermal indicator to take further account of sun and wind. An additional variable, resting heart rate is included in the enhanced model, improving the overall prediction power of the original model. A refined and enhanced heat stress model is now constructed to predict a worker's physiological responses to different meteorological factors, work related factors, and personal factors. More specific heat stress guidelines can be formulated based on objective and scientific parameters to safeguard workers' health and safety.

Workers in different trade activities may have different degrees of susceptibility to heat stress. A trade by trade specific study would better reflect the real situation. Although this study applies specifically to the bar bending and fixing trade, more work is needed to further investigate other trades and to other countries to provide a holistic view in future. In the light of the enhanced heat stress model, a set of good practices and indices, such as work duration, work-rest pattern, can be developed to ensure the health and safety of site personnel working in hot weather. This would be of tremendous value in better safeguarding workers' health and safety by reducing the occurrences of heat stress on site.

11. Acknowledgements

This project is funded by a grant from the Research Grants Council of the Hong Kong Special Administrative Region, China (RGC Project No. PolyU510409). The support from the Hong Kong Housing Authority, Sun Hung Kai Properties Ltd, Yau Lee Construction Co Ltd, and China State Construction Engineering (HK) Ltd, is deeply appreciated. The research team is also indebted to the technical support from technicians of Hong Kong Polytechnic University and Hong Kong Institute of Education. In particular, the participation of front-line rebar workers in this experimental study is gratefully acknowledged. This paper forms part of the research project titled “Experimental research on health and safety measures for working in hot weather”, from which other deliverables will be produced with different objectives/scopes but sharing common background and methodology. The authors also wish to acknowledge the contributions of other team members including Prof Francis Wong, Dr Daniel Chan, Dr Del Wong, Prof Esmond Mok, Dr Geoffrey Shea, Dr Min Wu, Dr Herbert Biggs, Dr Donald Dingsdag, and Miss Alice Guan.

12. Reference

American College of Sports Medicine, (1984),. “Prevention of thermal injuries during distance running”, *Medical Journal of Australia,Vol. 141,* pp.876 - 9.

American College of Sports Medicine,(1987), “American College of Sports Medicine Position Stand on the prevention of thermal injuries during distance running”, *Medical & Science in Sports Medical Science & Sports Exercise Exercise*,Vol 19, pp.529-33.

American College of Sports Medicine(2008), “ACSM’S Health-Related Physical Fitness Assessment Manual”2nd Ed, Lippincott Williams & Wilkins, . pp. 59.

Apple Daily (2007), “Worker died from heat stroke in golf course (in Chinese)”, 24 July, available at: http://www1.hk.apple.nextmedia.com/template/apple/art_main.php?iss_id=20070724&sec_id=4104&art_id=7359016

Apple Daily (2008),“Hong Kong extremely hot: Lady’s Market in Mongkok 40℃ (in Chinese) ”, 25 July, available at: http://www.aboluowang.com/news/data/2008/0725/article_54640.html

Apple Daily (2009), “10% bar fixers have suffered from heat stroke (in Chinese)”,5 July, available at: http://hk.apple.nextmedia.com/realtime/art_main.php?iss_id=20090705&sec_id=6996647&art_id=12953474

Apple Daily(2010), “Worker died from heat stroke in a falling accident (in Chinese)”, 19 Sep, available at: http://hk.apple.nextmedia.com/realtime/art_main.php?iss_id=20100918&sec_id=6996647&art_id=14465015

American College of Sports Medicine, (1996), “Position stand on heat and cold illnesses during distance running”, *Medical & Science in Sports & Exercise*, Vol 28 No. 12, pp. i–x.

Balasubramanian, V., and Prasad, G.S. 2007,“Manual bar bending- An occupational hazard for construction workers in developing nations”, *ASCE Journal of Construction Engineering and Management*, Vol. 33 No.10 , pp. 791-797.

Black, K. (1997), Business statistics: Contemporary decision making, West Publishing Company, St. Paul.

Borg, G.A. (1990), "Psychophysical scaling with applications in physical work and the perception of exertion, Scandinavian Journal of Work", *Environment & Health*,Vol 16 (Suppl)No.1 pp. 55–58.

Brotherhood, J.R. (1987), "The practical assessment of heat stress", In: *Heat Stress: Physical exertion and environment.* Eds: Hales, J.R.S. and Richards, D.A.B. Elsevier Science Publishers B.V. (Biomedical Division), pp.451-468.

Brotherhood, J.R. (2008), " Heat stress and strain in exercise and sport", *Journal of Science and Medicine in Sport*, Vol 11No.1, pp.6-19.

Budd, G. M. (2008), "Wet-bulb globe temperature (WBGT) – its history and its limitations", *Journal of Science and Medicine in Sport*, Vol 11, pp. 20-32.

Buonanno, G., Frattolillo A. and Vanoli, L.(2001), "Direct and indirect measurement of WBGT index in transversal flow." *Measurement*, Vol 29 No.2, pp.127-135.

Burr, R.E. (1991), "Heat illness: a handbook for medical officers." *USARIEM, Natick, MA*., Report No. 91-3, available at: http://handle.dtic.mil/100.2/ADA238974

Chan, APC, Wong, FKW, Yam, YCH, Chan, DMW, Mok, ECM, Shea, GYK, Guan, Y, Chung, JWY, Biggs, H, and Dingsdag, D (2011) "A research framework for assessing the effects of heat stress on construction workers". *Proceedings of 6th International Structural Engineering and Construction Conference, ISEC06 – Modern Methods and Advances in Structural Engineering and Construction*, 21-26 June, 2011, Zurich, Switzerland, 485-489.

Chaurel, C., Mercier-Gallay, M., Stoklov, M., Romazini, S. and Perdrix, A.(1993), "Environmental stresses and strains in an extreme situation: the repair of electrometallurgy furnaces", *International Archives of Occupational and Environmental Health*, Vol 65, pp.253–258.

Construction Industry Council, (2008), "Guidelines on site safety measures for working in hot weather", Publication No.2. Version 1, available at: http://www.hkcic.org/files/eng/documents/Publications/Working_in_hot_weather.pdf

Department of Health, HKSAR Government (2010), "Preventive measures against heat stroke and sun burn", 6 July, available at: http://www.dh.gov.hk/english/press/2010/100706-3.html

De Vaus, D.A. (1996), Surveys in social research, 4th Ed. London: UCL Press.

Environmental Protection Department, (2007), "API and air monitoring background information" http://www.epd-asg.gov.hk/english/backgd/calcu.html

Fellows, R. and Liu, A. (1997), “Research methods for construction”, Wiley-Blackwell.

Fogleman, M., Fakhrzadeh, L. and Bernard T.E. (2005), “The relationship between outdoor thermal conditions and acute injury in an aluminum smelter.” *International Journal of Industrial Ergonomics*, Vol 35 No.1, pp. 47-55.

Foster, C., Florhaug, J.A., Franklin, J., Gottschall, L., Hrovatin, L.A., Parker, S., Doleshal P .and Dodge, C. (2001), “A new approach to monitoring exercise training”, *Journal of Strength and Conditioning Research*, Vol 15, No.1, pp. 109-115.

Froom, P., Krisal-Boneh, E., Ribak, J. and Caine, Y.G. (1992), “Predicting increases in skin temperature using heat stress indices and relative humidity in helicopter pilots.” *Israel Journal of Medical Sciences,* Vol 28, pp. 608–610.

Glantz, S.A. and Slinker, B.K. (1990), *Primer of Applied Regression and Analysis of Variance*. McGraw-Hill.

Grimmer, K., King, E., Larsen, T., Farquharson, T., Potter, A. and Sharpe, P. (2006), “Prevalence of hot weather conditions related to sports participation guidelines: a South Australian investigation” *Journal of Sports Science and Medicine*, Vol ,9, pp. 72—80.

Gun, R.T. and Budd, G.M.(1995), “Effects of thermal, personal and behavioral factors on the physiological strain, thermal comfort and productivity of Australian shearers in hot weather”, *Ergonomics,* Vol 38, pp.1368–1384.

Hancher, D.E. and Abd-Elkhalek, H.A. (1998), “The effect of hot weather on construction labor productivity and costs”, *Cost Engineering*, Vol 40 No.3 pp. 2-6.

ISO 7243, (1989), “Hot environments-estimation of the heat stress on working man, based on the WBGT-index (wet bulb globe temperature).” *Geneva: ISO.*

Japan International Center of Occupational Safety and Health, (2001), “Japan Construction Safety and Health Association Visual Statistics of Industrial Accidents in Construction Industry”, available at: http://www.jniosh.go.jp/icpro/jicosh-old/english/statistics/jcsha/index.html

Jarkas, A.M. (2010), “The influence of buildability factors on rebar fixing labour productivity of beams.” *Construction Management and Economics*, Vol 28 No.5, pp. 527–543.

Kähkönen, E., Swai, D., Dyauli, E. and Monyo, R. (1992), “Estimation of heat stress in Tanzania by using ISO heat stress indices.” *Applied Ergonomics*, Vol 23 No.2, pp. 95-100.

Kannel, W.B. D'Agostino, R.B, and Cobb, J.L. (1996), “Effect of weight on cardiovascular disease”, *American Journal of Clinical Nutrition,* Vol 63 No.3, pp. 4195-4225.

Kannel, W.B., Kannel, C., Paffenbarger R.S. and Cupples, L.A. (1987), Heart rate and cardiovascular mortality: The Framingham Study. American Heart Journal Vol 113 No 6, pp. 1489-1494.

Kim, J. O. and Mueller, C. W. (1978), Factor analysis—Statistical methods and practical issues, Sage, Beverly Hills, Calif.

Labour Department. (2008).“Prevention of Heat Stroke at Work in a Hot Environment.” http://www.labour.gov.hk/eng/news/PreventionOfHeatStrokeAtWork.htm

Leedy, P.D. (1997),. “Practical research: planning and design.” 6th ed. New Jersey: Merrill.

McDermott, B.P., Lopez, R.M. and Casa, D.J., (2008), “Exertional heat stroke basics: What strength and conditioning coaches need to know?” *The Journal of Strength and Conditioning Research Corner*, Vol 30 No.3 pp. 29-32.

Montgomery, D.C., Peck, E.A.and Vining, G.G. (2001), Introduction to linear regression analysis, 3rd Ed. New York: Wiley

Montain, S.J., Latzka, W.A. and Sawka, M.N. (1999), “Fluid replacement recommendations for training in hot weather”, *Military Medicine*,. Vol 164 No 7, pp. 502–508.

Moran, D.S. and Pandolf, K.B. (1999). “Wet Bulb Globe Temperature (WBGT)—to what extent is GT essential?” *Aviation, Space, and Environmental Medicine* Vol 70, pp. 480–484.

Moran, D.S., Pandolf, K. B., Shapiro, Y., Laor, A., Heled Y. and Gonzalezb, R. R. (2003), “Evaluation of the environmental stress index for physiological variables.” *Journal of Thermal Biology*, Vol 28 No.1, pp. 43-49.

National Institute for Occupational Safety and Health (1986), “Occupational exposure to hot environments.”Department of Health and Human Services, Washington, DC, Report No.: DHHS86-113.

Norusis, M.J. (2008), SPSS 16.0 Statistical Procedures Companion, Second Edition, Prentice Hall.

Schroeder, L. D., Sjoquist, D. L. and Stephan, P.E. (1986), “Understanding regression analysis.” Sage Publications, pp. 31-32.

Singh, A.P., Majumdar, D., Bhatia, M.R., Srivastava, K.K. and Selvamurthy, W. (1995). “Environmental impact on crew of armoured vehicles: effects of 24 h combat exercise in hot desert.” *Inernational. Journal of. Biometeorol.*, Vol 39, pp.64–66.

Sports Medicine Australia. (2006), “Policy: Preventing heat illness in sport”, available at: http://www.sma.org.au/pdfdocuments/Heat policy.pdf.

Steadman, R.G. (1979), “The assessment of sultriness Part I: a temperature-humidity index based on human physiology and clothing science." *Journal of Applied Meterorology,* Vol 18, pp. 861–873.

The Hong Kong Polytechnic University (2008). Guidelines for ethics review of research/teaching projects involving human subject, available at: https://www2.polyu.edu.hk/research_handbook/appendix/ap6g.pdf

US Department of Labor. (2004), "Occupational Safety & Health Administration. Safety and Health topics: Heat Stress", United States: US Department of Labor.

Wittink, D.R. (1988), "The application of regression analysis", Massachusetts: Allyn and Bacon Inc.

Yaglou, C.P. and Minard, D. (1957), "Control of heat casualties at military training centers", .*Archives Indutrial. Health.,* Vo*l* 16, pp. 302–305.

Full name: Albert P.C Chan

Affiliation: Dept. of Building and Real Estate, Hong Kong Polytechnic University

E-mail address: bsachan@inet.polyu.edu.hk

Full international contact details

Tel.: (852) 2766 5814

Fax.: (852) 2764 5131

Address: Dept. of Building and Real Estate, The Hong Kong Polytechnic Univ., Hung Hom, Kowloon, Hong Kong.

Brief professional note

Prof. Albert Chan is a Chartered Builder, Engineer, Project Manager, and Surveyor by profession. Prof. Chan has worked in a number of tertiary institutions both in Hong Kong and overseas, including City Polytechnic, the predecessor of the City University of Hong Kong, University of South Australia and The Hong Kong Polytechnic University. He was a Senior Lecturer and Deputy Head of the School of Building and Planning at the University of South Australia. Prof. Chan joined the Department of Building and Real Estate in 1996 and is currently an Associate Head, and Chairperson of the Departmental Teaching and Learning Committee. Prof. Chan has been commissioned by a number of organizations to provide consultancy services in project management and construction economics. Some of the major clients include: Department of Labour and Industry of the South Australian Government, Department of Building and Construction of the City University, KCRC, MTRCL, Hong Kong Jockey Club, Hong Kong Housing Authority, and the Environment, Transport and Works Bureau of the HKSAR Government. He has produced over 500 publications in refereed journal papers, international refereed conference papers, consultancy reports, and other written outputs. He has won a number of prestigious research paper and innovation awards such as the 1995 Fred Wilson Memorial Prize, the Year 2000 Best Safety Paper Gold Prize Award, a Commemorative Medal in the CIOB 2001 Research Papers Competition, The CIOB Innovation Achievers Award for 2008/09, Gold Medal with the Congratulations of the Jury in Geneva, 2008, and the Award of High Scientific and Technological Level of the Invention, 2008. Prof. Chan holds an MSc in

Construction Management and Economics at the University of Aston in Birmingham, and a PhD in Project Management at the University of South Australia. Prof. Chan maintains good links with overseas institutions. He has been an Adjunct Professor of the Queensland University of Technology, the University of South Australia, and the Bond University in Australia; and the Huaqiao University of the PRC. Prof. Chan was also a Founding Director of Construction Industry Institute, Hong Kong, which was a joint research institution developed by the industry and the academia.

Full name: Michael C.H. Yam

Affiliation: Dept. of Building and Real Estate, Hong Kong Polytechnic University

E-mail address: bsmyam@polyu.edu.hk

Full international contact details

Tel.: (852) 2766 4380

Address: Dept. of Building and Real Estate, The Hong Kong Polytechnic Univ., Hung Hom, Kowloon, Hong Kong.

Brief professional note

Dr. Michael Yam obtained his BSc. in Civil Engineering with Distinction and MSc. at the University of Alberta, Canada and completed his PhD degree at the same University in 1994. He subsequently was appointed as a research engineer at the University before returning to Asia in 1995. Prior to joining the Department of Building and Real Estate in early 2002, Michael has spent several years with the University of Macau as Assistant Professor of Civil Engineering, as well as the Hong Kong Technical College as Lecturer. He has also obtained consultancy experience in the areas of the design and construction of both reinforced concrete buildings and structural steelworks in Hong Kong. Michael is a member of the Hong Kong Institution of Engineers, Institution of Professional Engineers New Zealand, Institution of Engineers, Australia and the American Society of Civil Engineers.

Full name: Joanne W.Y. Chung

Affiliation: Dept. of Health and Physical Education, The Hong Kong Institute of Education

E-mail address: joannechung@ied.edu.hk

Full international contact details

Address: Department of Health and Physical Education, Hong Kong Institute of Education, 10 Lo Ping Road, Tai Po, New Territories, Hong Kong

Brief professional note

Professor Joanne Chung is currently the Chair Professor of Health Studies and the Head of Department of Health and Physical Education of the Institute. She is also the Co-Principal Investigator of the Centre for Integrative Digital Health Centre of The Hong Kong Polytechnic University. Her creativity, leadership and perseverance in research activities in the emerging and potentially lucrative field of digital health and study of pain are especially noteworthy, having resulted winning of many international prizes in the past years and has published extensively. She is a pain specialist in both research and clinical practice. She has researched and developed an integrative pain management protocol for patients afflicted with cancer, chronic or idiopathic pain. Prof. Chung has also devoted her effort in developing school health. Old habits die hard. Good healthy habits and lifestyles have to start young. Her ambition is to instill health concepts into our young children as they are the masters of our future society. Good health education and practice will not just cut health financing cost but also give this place a vibrant and joyful society.

Full name: Wen Yi

Affiliation: Dept. of Building and Real Estate, Hong Kong Polytechnic University

E-mail address: bsyw@inet.polyu.edu.hk

Full international contact details:

Tel.: (852) 2766 4262

Fax : (852) 2764 5131

Address: Dept. of Building and Real Estate, The Hong Kong Polytechnic Univ., Hung Hom, Kowloon, Hong Kong.

Brief professional note

Miss. W. YI, BEng, MPhil, completed her MPhil at Faculty of Construction Management and Real Estate, Chongqing University. She is currently a research assistant for the heat stress project at the Department of Building and Real Estate, The Hong Kong Polytechnic University

Response to Reviewer's Comments

Journal Name:	Journal of Facilities Management
Manuscript ID:	JFM-Jun-2011-0013
Paper Title:	Developing a heat stress model for construction workers

Reviewer 1	**Authors' Responses**
1. Originality: Does the paper contain new and significant information adequate to justify publication?: The issue heat stress is very real risk in the construction industry. This type of information could be helpful in addressing this topic.	**Noted.**
2. Relationship to Literature: Does the paper demonstrate an adequate understanding of the relevant literature in the field and cite an appropriate range of literature sources? Is any significant work ignored?: While the literature on heat stress may be extensive, it is limited in its applications in the construction industry. The literature review is adequate.	**Noted.**

3. Methodology: Is the paper's argument built on an appropriate base of theory, concepts, or other ideas? Has the research or equivalent intellectual work on which the paper is based been well designed? Are the methods employed appropriate?: While the methodology may be appropriate, it is not explained very well. There is a discussion in the introduction about "an original" study on heat stress. It is not clearly explained that the authors are actually referring to their own work. At least that is what I could infer. The fact that there were 281 cases indicates that it is the same. While it is stated that there were 10 workers who voluntarily participated in the study, there is no indication of how many workers were asked to participate. Also, how many workers declined to participate. While these were from 4 different projects, how were the ten workers distributed among them? The introduction mentions the original model, but no background is given for it.	Further information regarding the background of original heat stress model has been provided to clearly explain that the authors are actually referring to their own work. Please refer to the revised section of "The original heat stress model". As suggested by the reviewer, the distribution of 10 participants from 4 different construction sites is added and illustrated in Fig.4.
4. Results: Are results presented clearly and analysed appropriately? Do the conclusions adequately tie together the other elements of the paper?: The conclusions would be strengthened if the authors would summarize in layman's terms what the results really mean. This is lacking from the paper. It appears as if the model is validated by using data from only one worker. This seems to be akin to manipulating the data. Why were data from other workers not included? This should be explained.	The conclusions were re-written in layman's terms. Regarding to the data validation, in total 281 sets of synchronized data from 10 participants were collected during the summer time of 2010. 271 sets data from 9 participants were used for developing the heat stress model, and the remaining 10 sets of data from 1 participant were reserved for validating the model.

5. Implications for research, practice and/or society: Does the paper identify clearly any implications for research, practice and/or society? Does the paper bridge the gap between theory and practice? How can the research be used in practice (economic and commercial impact), in teaching, to influence public policy, in research (contributing to the body of knowledge)? What is the impact upon society (influencing public attitudes, affecting quality of life)? Are these implications consistent with the findings and conclusions of the paper?: A more grounded summarization of the results would help to explain the true contribution of this study. The implications for changing work practices are not clearly defined or explained.	As mentioned earlier, the conclusions were re-written in layman's term to spell out the true contribution of this study.
6. Quality of Communication: Does the paper clearly express its case, measured against the technical language of the field and the expected knowledge of the journal's readership? Has attention been paid to the clarity of expression and readability, such as sentence structure, jargon use, acronyms, etc.: In general, the paper is well written. Some proofreading would be helpful to avoid some of the words that are not separated by spaces.	Proofreading has been done to the entire paper as recommended by the reviewer.