Hong Kong in summer (June - October) is hot and humid. Construction workers have to undertake physically demanding activities in these hot and humid conditions. They have to perform outdoor physical work and often in confined spaces. They are vulnerable to heat stress in summer as heat stroke has already caused a number of deaths. Apart from fundamental practice notes and guidelines on working in hot weather, health and safety measures associated to heat stress measured by scientific and clinical parameters are urgently needed. This paper provides an initial report of a research project funded by the Research Grants Council (RGC) of the HKSAR. The aim of this study is to develop a set of indices measured by clinical and scientific methods to detect impending attacks of heat stress. These indices would be of tremendous value in better safeguarding workers’ health and safety by reducing the occurrences of heat stress on site. This paper firstly reports on the statistics of construction incidents arising from heat stress. Qualitative and quantitative research methods applied in conducting the research are discussed. It is believed that the construction industry and the government would benefit a lot as a result of this study.

Keywords: heat stress, clinical parameters, thermal work limit (TWL), rate of perceived exertion (RPE), construction working condition.
1. Introduction

Hong Kong weather in summer can seem like swimming through soup. The sun beats down, the air is laced with the humidity higher than 80%, and shirts become tissues to stop sweat. This misery is a constant threat to construction workers working in Hong Kong’s summer days. One of the most commonly used solutions for outdoor construction workers in summer days is to have a rest in day time and to work in the night. However, it is not possible in Hong Kong since there is no difference in ambient temperature and humidity due to the large effect of Green house induced by the surrounded Pacific.

The ultimate goal of this study is to derive a set of indices measurable by clinical and scientific methods enabling detection of impending attacks of heat stress offering the prospect of increased safety, particularly, at this stage, for bar benders and fixers. The significance of such exploration lies in both its generic scientific value and its direct applicability.

2. Literature Review

2.1 Effects of heat stress on Construction Industry

Since many of verifiable deaths due to the heat stress have been reported from construction industry, the hazardousness of the hot weather to the outdoor working workers has been alarming and drawn an attention by the government, government-related bodies and the construction industry. The issue of working in hot weather has also been of concern to the Construction Industry Council (CIC). The CIC has set up a task force on working in hot weather and has just promulgated a set of guidelines on preventing heat stress. The Occupational Safety and Health Act (Department of Labor. Occupational Safety & Health Administration, 2004) have protected construction workers from heat related hazards at work since 1970. Heat stress can be reduced by providing shelter, blowing fans, sufficient rest breaks and adequate cool drinks to replace the water lost as sweat (Labour Department, 2004; Construction Industry Council, 2008). Although the number of very hot days was fairly steady between 1998 and 2006, the number was annoyingly high in 2007. In Hong Kong, the construction industry is found to be more susceptible to heat stress than all other industries. Temperatures inside the enclosed segment void were much higher than atmospheric temperature and ventilation was inadequate (Department of Health, 2008). It was reported that there is a huge difference between the officially reported temperature and the actual working environment. This will put construction workers at higher risks because they have to work on top of structures without shading.

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, 2008), there is a lack of scientific research specific to the
A research framework for assessing the effects of heat stress on construction workers

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construction industry in Hong Kong on which to put forward safety measures combating heat stress based on reliable clinical parameters. This study would fill in this gap by using Clinical Experimental Design (CED) and Remote Sensing (RS) technology to establish indices to detect impending attacks of heat stress and by recommending pertinent health and safety measures.

2.2 Effects of heat stress on Construction workers

The common heat related disorders are heat syncope (fainting), heat exhaustion, and heat stroke (Construction Industry Council, 2008). Heat stroke is a systemic inflammatory response with a core temperature > 40.6°C and associated clinical manifestations by mental status changes (anxiety, confusion, bizarre behavior, loss of coordination, hallucinations, agitation, seizures and often coma) (Bouchama & Knochel, 2002; Jones-Laskowski, 2000; Stillwell, 2002; McDermott et al, 2008). Moreover, it is most often accompanied by acute symptoms such as extreme fatigue, hot skin or heavy perspiration, nausea, vomiting, diarrhea; and reddened faces are frequently an early indicator (Pluth, 2004).

Organizational factors include insufficient work to rest ratios, increased physical activity at the hottest times of the day, insufficient maintenance of proper hydration and not varying the duration and frequency of physical activity based on environmental conditions (Casa et al, 2005; Rav-Acha et al, 2004).

In Hong Kong, the Guideline Notes on Health Hazards in Construction Work was published by the Labour Department in 2004. Despite the publication of these guidelines, health and safety measures linked up to heat stress measured by scientific and clinical parameters are still lacking and hence the value of the proposed study.

3. Research Framework

The research will combine literature reviews, structured interviews, clinical experimental studies, field studies, and focus group meetings to collect information and data on heat stress based on reliable clinical and environmental parameters.

Task 1. Structured Interviews

In this phase, about twelve targeted workers will be interviewed face-to-face, who are selected from government organizations, semi-government organizations, statutory
organizations, major contractors, trade associations, and labour unions. The following issues will be investigated with various stakeholders to gain a thorough understanding of the magnitude of heat stress related incidence in the construction industry and the current health precautionary measures for workers in hot weather:

a) Interviewees' awareness of heat stress related incidence in the construction industry.
b) Interviewees' awareness and their perceived effectiveness of basic guidelines on health and safety measures in hot weather.
c) Case details (what, when, where, how, why, and consequences) of heat stress related incidences.
d) Current health and safety measures adopted by interviewees' organizations for working in hot weather.
e) Recommendations and strategies for improving health and safety measures for working in hot weather.

**Task 2. Clinical Experimental Studies**

Heat stress evaluation is generally based on meteorological parameters and physiological parameters which will be measured and monitored to identify the physiological limit values at different heat and humidity exposures. Clinical experimental studies, having at least thirty data sets in each experimental combination, will be conducted in a climatic chamber at The Hong Kong Polytechnic University (PolyU). The climatic chamber can have variable temperature and humidity settings. The range of the settings is as follows: temperature from 10°C to 40°C, and relative humidity from 30% to 80% (Walter™-Sweating Manikin Lab, 2008). Subjects will be asked to perform heavy duty activities which require metabolic heat up to 580W; and at different climatic conditions, which will be varied from 30-40°C dry bulb temperature and 40-80% relative humidity, simulating the typical work activities, ambient temperature and relative humidity during summer times in Hong Kong. Lu's experimental procedure (Lu, S et al, 2007) will be applied in the clinical experimental studies. Subjects will be tested under nine experimental combinations. Each subject will be asked to undertake activities under three experimental combinations in a 3-hour timeslot, with breaks in between to ensure that subject has sufficient rests before taking on the next assignment. The combinations of temperature and relative humidity will be assigned randomly to the subjects. Prior to the experiment, subjects will be asked to rest at a cool temperature for 30 minutes to stabilize their body temperature and heart rates. Whilst taking the rest, subjects will be asked to complete a demographic data collection sheet which includes questions on sleep, smoking, drinking and diet history. Different physical parameters will then be measured before and after subject to experimental conditions in the climatic chamber. The maximum heat exposure duration inside the climatic chamber for each experiment will be 30 minutes unless subjects cannot bear the heat exposure or some abnormal symptoms appear. A qualified nurse will be engaged throughout the clinical experimental studies to monitor any abnormal symptoms and to provide immediate medical treatment if need arises. Subjects will be allowed to drink water as and when they desire. Physiological measurements and environmental measurements will be
measured and recorded for analysis. Unpleasant symptoms will be self reported by a Visual Analogue Scale (VAS) as and when subjects carry out the prescribed tasks inside the climatic chamber. VAS is a self-report device used extensively to measure such complaints (Gift, A.G. 1989). Results generated from the clinical experimental studies will provide a good reference point for the field studies at a later stage.

**Task 3. Field Studies**

Similar physiological and environmental variables will be measured on different construction sites between June and October, the hottest season in Hong Kong. Different stages of construction from foundation works to core structural works will be studied to capture a wide spectrum of empirical data. The amount of solar radiation that the bar bending and fixing workers receive varies when they are under shade instead of under direct sunlight. Locations where the subjects work will therefore be recorded to ascertain the effects of heat stress under shade and under direct sunlight. Remote Sensing technology will be adopted to track subjects' positions in outdoor environment. Subjects' positions will be sent back to a tracking server at defined time interval. Subjects' positions will be displayed in a Geographic Information System (GIS) of the tracking server in real time, as well as stored in a database for further analysis together with other physiological and environmental data collected by temperature and pressure sensors. Site structure and development drawings, plans, and digital photographs of physical working conditions at the time of data collection will be correlated with the physiological and environmental data to identify the effects of working areas with features such as reflected heat, partial shade, confined spaces etc.

**Task 4. Data Analysis**

Descriptive statistics and inferential statistics will be employed for data analyses. T-test and MANOVA will be applied to discover the variables that would significantly affect the bar bending and fixing workers’ ability to heat tolerance and heat exposure limits. Correlations of environmental variables, physiological variables and subjective ranking under different combinations of metabolic rate, clothing and solar radiation will be calculated. These correlations will enable us to identify the relation between heart rate and oral temperature at heat exposure limits; the variation on blood pressure during heat exposure; and sweating rate at heat exposure limits, etc. Changes of physiological variables at heat exposure limits are a valid method of evaluating a person’s ability for heat tolerance (Lu and Zhu, 2007). Analyses within compare the thermal work limit, rate of perceived exertion with energy expenditure of data collected from the clinical experimental studies and field studies will enable us to evaluate heat tolerance ability of subjects and provide reference values/indices of physiological variables at heat and humidity
exposure limits. The data analysis quantitative research methods applied in conducting the research is discussed.

4. Conclusion

Construction workers are inevitably to undertake outdoor physical work or even in confined spaces in hot and humid weather. Apart from fundamental practice notes and guidelines on working under extreme conditions, health and safety measures associated to heat stress measured by scientific and clinical parameters are urgently needed and adopted by the industry. Workers in different trade activities may have different degrees of susceptibility to heat stress. It is expected that construction workers could prevent from suffering heat stress by the measurable indices establishment. This would be of tremendous value in better safeguarding workers’ health and safety by reducing the occurrences of heat stress on site.

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