Using the Thermal Work Limit as an Environmental Determinant of Heat Stress for Construction Workers

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Abstract: Construction workers are vulnerable to heat stress in summer as evidenced by deaths and injuries caused by heat stroke. Over the past centuries, many heat-stress indices have been developed to assist with the management of these problems. To address this pressing need of the industry, an enhanced model based on a multi-dimensional environmental indicator, the thermal work limit (TWL) index, is developed. Field studies were conducted between July and September 2010 in Hong Kong on ten apparently healthy and experienced construction rebar workers. Based upon 281 sets of synchronized meteorological and physiological data collected from four different construction sites, physiological, work-related, environmental, and personal parameters were measured to construct the heat-stress model. Multiple linear regression showed that a total of ten determining factors are able to predict the workers' subjective rating of perceived exertion (RPE) (adjusted $R^2 = 0.79$, $p < 0.05$). The accuracy of the TWL heat-stress model was found to be statistically acceptable (mean absolute percentage error = 4.3%, Theil's U inequality coefficient = 0.003). Alcohol-drinking habits, age, and work duration are the three most important predictors to determine the physiological responses of construction workers. The model reported in this paper provides a scientific prediction of the reality, which may benefit the construction industry to produce solid guidelines for workers working in hot weather. **DOI: 10.1061/(ASCE)ME.1943-5479.0000162.** *© 2013 American Society of Civil Engineers.*

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Introduction

Workers, soldiers, and travelers are often exposed to severe environmental heat stress, which may deteriorate work efficiency and productivity, and may even threaten survival (Kaming et al. 1997; Liu et al. 2011; Nielsen 2006; Rojas and Aramvareekul 2003). It is expected that the physiological heat strain experienced by an individual is affected by the total heat-stress exposure. Many previous research studies have estimated the stress inflicted by a wide range of work conditions and climate, estimated the corresponding physiological strain, and combined these into a single heat-stress index (Epstein and Moran 2006). A heat-stress index is a single value that integrates the effects of the basic parameters in any human thermal environment such that its value varies with the thermal strain experienced by the individual (Parsons 2003). Over 60 heat-stress indices have been developed (Parsons 2003) since Houghton and Yaglou (1923) developed the effective temperature (ET) scale, creating the first index of thermal comfort. This index was originally established to provide a method for determining the combined effects of air temperature and humidity on thermal comfort (Steadman 1979). Many cities in the United States issue excessive heat alerts based on a heat index (HI), which is a metric using two common meteorological values, i.e., temperature and relative humidity (Metzger et al. 2010).

The HI, although simple in terms of understanding and application, has its own limitations. Four basic elements, namely air temperature, mean radiant temperature, absolute humidity, and air movement are common parameters for evaluating the thermal environment. 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 indices (i.e., ET and HI) could underestimate or overestimate environmental warmth. Some agencies (American College of Sports Medicine 2007; Grimmer et al. 2006; Sports Medicine Australia 2008) recommend that a more embracing index, wet-bulb globe temperature (WBGT), be used instead. The WBGT is the most widely used index in assessing heat stress, and has been adopted by the U.S. occupational health authorities and other national and international agencies as the basis of heat-stress standards (ACGIH 2000; ISO 2003; Ramsey and Chai 1983).

Although WBGT responds to all four elements of the thermal environment (Budd 2008), it is relatively insensitive to the cooling effect of air movement (Brake and Bates 2002a). In practice, WBGT is difficult to apply as it requires an estimation of the workers' metabolic rates, which will not only vary throughout a shift with different tasks performed, but also be voluntarily altered by self-pacing workers (Brake and Bates 2002a). Because of the above limitations, WBGT is considered as an excessively conservative index of environmental heat stress (Miller and Bates 2007). A new generation of heat-stress indices that address the inadequacies of WBGT have emerged since the last decade.

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