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Evaluating the impacts of high-temperature outdoor working environments on construction labor productivity in China: A case study of rebar workers

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ABSTRACT

The purpose of this study is to provide industry practitioners with a better understanding of the impacts of high-temperature conditions on construction labor productivity. Such information could assist in the establishment of plans to prevent heat-stress injuries and help improve the safety and comfort of construction labor working environments. On-site WBGT (Wet Bulb Globe Temperature) data and labor productivity data related to direct work time, indirect work time and idle time were measured for two construction projects involving 16 rebar workers in the summer of 2014 in Beijing, China. The period from 14:00 to 15:00 was identified as the most hazardous for workers throughout the day, and the period from 07:00 to 09:00 was identified as the least hazardous time. Productivity models were further used to analyze the collected data. The model results demonstrated that high-temperature environments decrease labor productivity, with the percentage of direct work time decreasing by 0.57% and the percentage of idle time increasing by 0.74% when the WBGT increased by 1 °C. Moreover, the percentage of direct work time increased by 0.33% when the workers' experience increased by 1 year and decreased by 0.72% when the workers' age increased by 1 year. Overall, the results demonstrated that high-temperature environments impose heat stress on the human body and decreases labor productivity in the construction industry.

1. Introduction

Increases of temperature related to global climate change have continually drawn concern regarding the occupational health of the public. In 2013, the Intergovernmental Panel on Climate Change (IPCC) [1] reported that the land and ocean surface temperature had increased by approximately 0.85 °C since 1880, and the number and length of heat waves is estimated to continue increasing during this century. Increasing temperatures increase the occurrence of high temperatures in outdoor working environments. An outdoor environment is considered high temperature when the temperature exceeds 32 °C and the WBGT (Wet Bulb Globe Temperature) exceeds 25 °C [2,3]. High temperatures can impose heat stress on the cooling system of the human body, and when the reaction mechanisms for removing excess heat stop or slow down, heat illnesses can develop [4]. Thus, working environments and work activities that continuously expose people to high temperatures increase the risk of heat-related illness.

Traditionally, construction is a labor-intensive and physically demanding industry, and employees working in direct sunlight tend to be more vulnerable to high temperatures in outdoor working environments [5]. Worldwide, a large amount of evidence has indicated that high-temperature environments in the construction industry are harmful. For example, 31 fatalities related to outdoor environmental heat exposure were reported by the US Bureau of Labor Statistics (BLS), and 45% of the fatalities in 2013 were associated with the construction industry [6]. In Hong Kong from 2007 to 2011, newspapers reported that 43 heat and stress-related accidents, including 11 fatalities, occurred on construction sites [7]. Therefore, the data show that high temperatures are harmful to the health of construction laborers; however, contractors rarely consider this issue seriously.

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Productivity represents a relationship between the output and the associated input in a production process. Because labor costs account for nearly 30–50% of the total cost of a project and manpower is the dominant or only productive resource in the construction industry, labor productivity is commonly treated as a single factor for measuring productivity [8,9]. The American Association of Cost Engineers International (AACE International) [10] also defines productivity in the construction industry as the “rate of output per unit of time or effort, usually measured in labor hours”. Construction labor productivity can be explained mathematically by the following equation:

$$\textit{Construction labor productivity} = (\textit{Unit output})/(\textit{Labor inputs}) \quad (1)$$

The productivity of workers in outdoor high-temperature environments may decrease because of workers automatically decreasing their activity to prevent their bodies from generating excessive heat [11]. In addition, the side effects of working in high-temperature environments are reflected in delays, irritability, restlessness and reduced enthusiasm in daily work [12]. Considering the negative impacts of high-temperature environments on labor productivity, the relationships between these two factors is an important topic of research [13,14]. However, studies on high-temperature environments and labor productivity is focusing in other industries other than construction. For example, the National Electrical Contractors Association (NECA) [15] conducted an experiment to quantify the effects of humidity and temperature on the productivity of electricians and observed the highest productivity at 24 °C. Moreover, previous studies of the impacts of high temperatures in outdoor working environments on construction productivity present limitations that require further investigations with more realistic and comprehensive perspectives, including those listed below.

- On-site studies of high-temperature environments and labor productivity in China have not been performed. Certain relevant studies have been conducted in Hong Kong regarding construction laborers and heat stress; however, these studies did not involve direct measurements of labor productivity. Chan et al. [16,17] determined the optimal recovery time for construction rebar workers under heat stress after they had worked to exhaustion. Yi and Chan [18] optimized the work–rest schedule for construction rebar workers in hot environments and found that taking 15–20 min breaks every 115–120 min was the most suitable schedule.
- Most previous studies of high-temperature environments and labor productivity lack on-site data for support. For example, Hancher [19] used previously established theoretical equations to develop a hot-weather productivity model to estimate changes in the productivity of different construction processes in hot weather. Moreover, other studies conducted in controlled chambers have not been able to accurately simulate actual conditions. Zhao et al. [20] created formulas to estimate the heat tolerance and productivity of laborers within a chamber with controlled air temperature and humidity.
- Current methods used to measure productivity have limitations. Traditionally, labor productivity in the construction industry is measured in terms of hourly output [21], which is defined using the number of labor work hours as an input value to obtain the physical quantity of work as an output [22,23]. However, the production rates among different jobs can lead to differences in measured productivity, even when laborers perform the same type of work. For example, rebar workers are more efficient at tying wires for slab reinforcement than they are at tying wires for column reinforcement. Moreover, the current methods of measuring worker productivity under heat stress focus on the ratio of the allowable metabolic rate to the full metabolic rate. Brake [24] developed a heat stress index for assessing thermal stress and estimated changing work rates in certain environments by tracking metabolic rate changes. This method heavily depends on the average physiological conditions of the participants and ignores individual and regional differences. The actual labor productivity of a construction project is expected to vary according to different individuals or regions and is worthy of research.
- Previous studies used single average daily values to measure the WBGT and labor productivity variables and ignored time, which is also an essential factor that should be considered. For example, Thomas, Riley and Sanvido [25] studied how productivity changed with weather by using the average daily rates of task completion and a single temperature at a certain time of the day; thus, this method cannot reflect the exact high-temperature conditions and labor productivity over different periods of a day, which vary widely.

The aim of this study is to provide industry practitioners with a sound understanding of the impacts of high-temperature conditions on construction labor productivity during various periods of a day or year so that better policies may be established for preventing heat stress and increasing labor productivity. In this study, the authors conducted an on-site study in Beijing, China. Data based on continuous and direct observations of the outdoor working environments and construction laborers were collected to track changes in the on-site labor productivity and the outdoor heat stress at different times during a 54-day measuring period in the summer of 2014. Labor productivity was measured based on the direct work time, indirect work time and idle time, which are measures of efficiency in terms of time rather than completed work [26]. Next, productivity models were created to study the impacts of outdoor heat stress on construction labor productivity. The fatigue conditions of rebar workers during the day were also discussed.

2. Methodology

2.1. Selection of construction projects and target groups

In this study, two ongoing reinforced concrete building projects in Beijing, China were selected to measure the productivity and high-temperature environments during the summer of 2014. Reinforced concrete buildings are the most common type of building in China; thus, the measured projects are representative of buildings in China. Rebar workers were selected as the subject of research because rebar work accounts for a large portion of construction work. Moreover, rebar workers are exposed to high temperatures in outdoor environments and are relatively easy to observe on working platforms compared with other types of workers. Additionally, the working methods used in rebar work are simple and routine; therefore, the methods used by different laborers are similar and the work conducted by the selected laborers is representative. Finally, all of the selected rebar laborers are male, which is the main gender that performs work in this industry.

Both projects were constructed and managed by the Beijing Urban Construction Sixth Group Co. Ltd. The first project involved building a new hall in the library located on the Tsinghua University campus in the Haidian District (THUL). Overall, 8 rebar workers were engaged in the field measurements, which began on June 23 and ended on July 19, for a total of 27 days of data collection. The second project was the East Shahe Project in the Changping District