Investigation on heat stress of construction workers in summer in Chongqing, China

Longqian Li[1,2], *Hong* Liu[1,2], *Lu* Chen[1,2], *Jiaze* He[1,2]

[1]Joint International Research Laboratory of Green Buildings and Built Environments (Ministry of Education), Chongqing University, Chongqing 400045, China
[2] National Centre for International Research of Low-carbon and Green Buildings (Ministry of Science and Technology), Chongqing University, Chongqing 400045, China

Abstract. The heat stress of workers at construction sites in Chongqing, China, was studied in this paper. The investigation included measurement of environmental parameters, measurement of physiological parameters, questionnaire survey and tracking record of their self-regulation of the behaviour. Scaffolder, carpenter, porter, plasterer and handymen were taken as the main research subjects. Five subjects were selected daily to conduct a questionnaire survey and to measure their physiological parameters, 60 construction workers were investigated. The results show that in sizzling summer, the average effective Wet Bulb Globe Temperature (WBGTeff) is 35.8 ° C. Under these circumstances, workers are in a poor working environment based on some Chinese and international standards. During the experiment, the researchers recorded the work behaviour and self-regulation of workers. It is found that the average heart rate of workers with different job is significantly different, and the average metabolic rate of handymen is significantly lower than that of piling rig workers. Different type of workers should be protected by different protection rules to avoid suffering heat injury.

1 Introduction

With the economic development and social progress, people began to pay more and more attention to the occupational hazards in all kinds of work. In recent years, Wet Bulb Globe Temperature (WBGT) in various parts of the world has hit record highs in summer. In hot temperature environment, engaged in a certain intensity of manual labor, if not fully protected, easy to accumulate heat due to the body, causing the core temperature, leading to normal functioning of internal organs decline in body and water and salt imbalances and other issues. When the heat storage effect exceeds the physiological range of human body temperature regulation, it may lead to several types of heat diseases. In the summer of 2018, several cases of heat diseases have taken place in Chongqing City, Shaanxi Province, Jiangsu Province and Macao Special Administrative Region in China, causing dozens of people died, including outdoor workers such as construction workers and sanitation workers.

Although, as technology advances, labor in some extremely harsh environments has been replaced by various machines or equipment, much remains to be done by manual work, such as long-term outdoor work in the construction workers, sanitation workers, postmen. When the weather is hot outdoors in summer, these types of work are more susceptible to heat load.

Compared with other industries, the construction industry is more susceptible to high-temperature environments under summer high-intensity solar radiation[1]. At present, Chinese construction industry lacks standards for protecting workers in high-temperature environments, and its management level lags behind that of developed countries. The protection of workers is limited to such decrees as the《Notice on the Administration of Measures for the Administration of Heatstroke Prevention and Cooling Measures》. Laws, regulations, standards and protection systems to protect construction workers from heat damage need to be established. The purpose of this study is to investigate the working environment of the construction site and the health status of workers, and to provide reference materials for labor protection of workers in high temperature environments.

2 Research methods

2.1 Site investigation

This research mainly adopts the method of site investigation. A construction site in Banan District, Chongqing, China, was selected to conduct this research,during July to August in 2018. More than 500 workers work at the same time every day at the construction site. The climate of is hot in summer and cold in winter. The temperature in summer is mostly between 27.0 ℃ and 38.0 ℃, and the maximum temperature can reach 43.8 ℃. The hottest 15 days with temperatures above 35.0 ℃ were selected for research. The construction site of the job is generally divided into scaffolding workers, handymen , carpentry, porters, steel workers, bricklayer, etc, which contains the upper extremity exercise, lower extremity exercise and comprehensive exercise. In terms of schedule, during the hot summer, the managers arranged for workers to work from 6 am to 11 am and from 4 pm to 8 pm , avoiding the hottest hours.

The field studies included measurements of environmental and physiological parameters , questionnaires , and observations of workers' voluntary behavioral adjustments. Sixty workers with different work were randomly selected as subjects,five workers were tested daily, and each worker was tested for a half day for a total of fifteen days.

2.2 Measurement of environmental parameters

According to the site environment, WBGTeff was chosen to evaluate the workers' environment. WBGT (Wet Bulb Globe Temperature) is the most widely used direct indicator of thermal stress today, it is to deal with the event of heat casualties of US naval training [2] The index combines three environmental parameters of air temperature (Ta), natural wet-bulb temperature (Tnw) and black globe temperature (Tg), considering four basic environmental parameters such as dry bulb temperature, wet bulb temperature, radiation temperature and air velocity, can be applied to different environments. According to ISO 7243: 2017[3-6] ,WBGT is calculated as

Without solar load

$$WBGT=0.7t_{nw}+0.3t_g \quad (1)$$

With solar load

$$WBGT=0.7t_{nw}+0.2t_g+0.1t_a \quad (2)$$

These formulas are applicable to cotton work clothes (thermaI resistance of clothing is 0.6 clo and impermeability index is i_m=0.38). different clothing, especially with a different evaporative resistance, is likely to have a different effect on the heat stress level. For clothing materials and configurations different from standard work clothing, clothing adjustment values (CAVs) in WBGT temperature units are provided. The CAV is added to the measured WBGT to produce an effective WBGT($WBGT_{eff}$) that represents an estimate of the heat stress provided by the actual clothing worn as an equivalent environment.

$$WBGT_{eff}=WBGT+CAV \quad (3)$$

At the construction site, WBGT, air temperature, black globe temperature and air velocity were measured. Portable WBGT Thermal Index Device, model no. JTR10A (precision ±0.5℃) is used to measure WBGT, air temperature and globe temperature. KIMO handheld hot wire anemometer, model no. VT100 (precision ±0.1m/s) is used to measure air velocity.

2.3 Measurement of physiological parameters

The purpose of high-temperature environmental safety management is to monitor and control the impact of environmental heat load on human physiological heat stress and avoid the generation of heat diseases. The physiological response of workers in high temperature environments is extremely complex， which will also be directly affected by individual differences in workers. During work, sweat will take away salt and water in the body. Copious amounts of sweat cause a lot of body fluid loss, blood concentration increases, body temperature regulation ability decreases, heart rate increases, work efficiency decreases, and workers' heart rate, blood pressure and body temperature increase accordingly. Allow workers to rest when they reach the threshold they can withstand, and work again after a while when the body resumes. The main physiological parameters are heart rate, blood pressure, ear temperature and skin temperature.

The metabolic rate determines the degree of comfort or fatigue exposed to the thermal environment. Particularly in hot weather, a large amount of metabolic heat generated by muscle activity exacerbates heat stress, and a large amount of heat needs to be dissipated in a sweat evaporation manner. Heart rate, as an alternative to measuring energy metabolism, suggests that there is a correlation between heart rate and energy metabolism during moderate-intensity physical activity[7-8]. At the same time, according to ISO 8996: 2004, in the case of dynamic work using major muscle groups, with only a small amount of static muscular load and in the absence of thermal strain and mental loads, the metabolic rate may be estimated by measuring the heart rate while working. The relationship between heart rate and metabolic rate can be written as:

$$HR=HR0+RM\times(M-M0) \quad (4)$$

M : metabolic rate(W/m^2)

M_0: metabolic rate at rest (W/ m^2)

RM : the increase in heart rate per unit of metabolic rate

HR_0 : the heart rate at rest, under neutral thermal conditions. (bpm)

$$RM=(HR_{max}-HR_0)/(MWC-M_0) \quad (5)$$

MWC :The maximum working capacity （W/ m^2）

$$Men:MWC=(41.7-0.22A)P^{0.666} \quad (6)$$

$$Women:MWC=(35.0-0.22A)P^{0.666} \quad (7)$$

$$HR_{max}=205-0.62A \quad (8)$$

A :age(in year)

P : weight (in kg)

Without affecting the normal work of workers under the premise, Polar heart rate sensor, model no.A300 (precision ±1%) is used to measure heart rate. Also, Barun IRT6520 thermoscan ear thermometer, DS1922T temperature logger and Omron U30 electric blood pressure monitor is used to measure ear temperature, skin temperature and blood pressure respectively.

2.4 Questionnaire

The collection of basic personal information includes height, weight, body temperature, average blood pressure, medication, related medical history, work clothes, feelings of the working environment, expectations, education level, time schedule, adjustments etc，which to some extent reflect the physical condition of the worker. Recording subjects' working hours, smoking frequency, drinking habits and leisure activities can reflect whether workers are overworked and their lifestyle is healthy. The follow-up survey mainly records the type of work of the tested workers, the situation of the workplace, the type of drinks, the frequency of drinking water, and adjustment methods

2.5 Experiment process

Firstly, a WBGT monitor was placed at the worker's workplace to record environmental parameters. The researchers then helped the workers fill out the questionnaire and gave the workers a heart rate belt, measuring their blood pressure and ear temperature. Subsequently, the experiment began, workers started working, their heart rate was continuously monitored, and the recording interval was 1 s. WBGT, air temperature, wet bulb temperature, black bulb temperature and wind speed are recorded every half hour. After the workers started working, the researchers observed and recorded their work behaviors and adjustment behaviors. After the work, the workers moved to a cool place to rest, and the researchers measured their heart rate, blood pressure and ear temperature.

3 RESULTS

In the survey, there were 16 carpenter, 12 scaffolding workers, 8 porters, 8 handymen and 16 other workers, for a total of 60 people. The youngest is 27 years old，who is the only worker aged 20 to 30. The oldest is 65 years old. There are 36 elderly people aged 50 to 70, accounting for 60% of the total number of surveys，showing a clear trend of aging. There are 17 workers with a working age of less than 5 years, 30 with a working age of 5 to 20 years, and 13 with a working age of more than 20 years. The workers with the largest working age are about 50 years who is 62 years old.

In the survey, 44 people said that they had experienced discomfort such as dizziness, chest tightness and tinnitus during the high temperature working hours in the afternoon. It is found that workers working in certain places are not conducive to relieving heat stress. For example, when workers are scaffolding, due to space constraints, workers with aloft work obviously drink less water than workers who work on the ground. Workers who plaster in poorly lit rooms. Due to workers eager to finish their work and get out of the dark environment. also drink water at a lower frequency. The other hand，Carbon dioxide in cigarettes reduces the amount of oxygen in the blood, while drinking affects the ability to respond and increases the workload of the liver, both of which cause the body to experience reduced function.however，the survey found that 38 workers had smoking behavior in addition to drinking water and chatting during work breaks. They think smoking helps to relieve their thermal stress.

3.1 $WBGT_{eff}$

Table 1 shows the values of average environmental parameters of workers during continuous working hours during the experiment period. According to the survey, workers wear clothes made of cotton or synthetic fibers, corresponding to work clothes and cloth coveralls in ISO 7243: 2017 annex F,both of which have zero adjustment values for clothing. Even avoiding the hot noon period, the average WBGTeff per day was as high as 29.6~40.2°C and the average fifteen-day air temperature was 38.4°C，average wet bulb globe temperature was 37.7°C. According to ISO 7243 and ISO8996, [4,6]The metabolic rate grades of several workers investigated were mainly moderate metabolic rate (300W) and high metabolic rate (415W). Considering that subjects are long-term construction workers,workers exercise moderate metabolic rates, at which time the values of WBGT reference limit for persons acclimatized to heat is 28.0 ° C. According to some of Chinese recommended standards, such as GB/T 17244, GB/T 4200 and GBZT 299.3, workers in a poor thermal environment are likely to cause health hazards and heat damage to workers. Require managers to take occupational health guardianship and sunstroke protection measures, heat stress monitoring and reduce the heat stress response and the unit of time ratio by adjusting the high-temperature work-rest system.

Table 1. environment parameters of the workplace

Day	Black globe temperature (°C)	Air temperature (°C)	Wet bulb temperature (°C)	$WBGT_{eff}$ (°C)
1	37.7	40.3	39.8	38.4
2	39.0	43.7	41.3	40.2
3	36.7	38.7	38.4	37.3
4	35.0	37.1	36.9	35.6
5	34.2	36.3	36.0	34.8
6	35.8	38.3	37.8	36.5
7	35.0	37.4	36.9	35.7
8	35.9	38.4	38.1	36.6
9	37.0	39.5	38.9	37.7
10	28.0	33.5	32.9	29.6

11	30.4	40.5	38.7	33.3
Average	35.0	38.5	37.8	35. 8

3.2 Heart rate and metabolic rate

Table 2 shows the average heart rate of workers in different types of work and the highest and lowest average heart rate and metabolic rate per minute in the experiment. The work of the scaffolding workers is to install, disassemble and transport the steel pipe. The working environment of the outer Scaffolding workers is poor, and the average metabolic rate, the average heart rate during work and rest are obviously higher than those of the indoor scaffolding work; carpenter cuts wooden boards and builds concrete molds. working in shaded areas, the average heart rate difference between work and rest is 21.45bpm. The work of the handyman is mainly for the auxiliary work of sorting and recycling steel bars、 wood molds and chiseling grooves. Working in shaded areas, the average heart rate difference between work and rest is 10.65bpm. Its labor intensity is low；The porters mainly carry heavy materials such as I-beams and sand, and most of them work in places where they are completely shaded，The labor intensity is large，but their working time is intermittent. The instantaneous heart rate of moving heavy objects increases greatly. They are rest while waiting for the tower crane to transport heavy loads. Its working environment is better than the hot outdoor，the average heart rate difference between work and rest is 19.16bpm. The plasterer is mainly for upper limb movement and works indoors，the average heart rate difference between work and rest is 14.00bpm. The work of the plumber is mainly for digging trenches, landfill pipelines and installing pipelines.

Working indoors, the average heart rate difference between work and rest is 16.76bpm；The piling rig worker operates the drill bit-pile to piling the well. , their needs to hold the drill bit by hand for a long time. It has a high labor intensity and works in an outdoor hot environment. The average heart rate during work is 126.60bpm, and the average heart rate at rest is 26.03bpm，the average heart rate of work time is higher than that of rest about 26.03bpm；According to ISO8996, this type of work is classified as a high metabolic rate level（200~260W/m^2）[4]；The steel workers work in the outdoor steel shed. The steel bars transported to the construction site by the factory are made into the shape required by the construction process. Since the construction organizer only arranged a small number of steel workers to work on site during the investigation, in order not to affect the progress of the project, only one steel worker participated in the survey. His resting average heart rate was 87.70bpm, the average heart rate during work was 116.72bpm, and the average heart rate changed 29.02 bpm. Metabolic rate of this worker reaches 213w/m^2. The average metabolic rate of all workers was 151.21 W/m^2.

3.3 The average metabolic rate with different types of work

The increase in heart rate mainly is due to heat stress and dynamic muscular load, under neutral thermal conditions.As is shown in Figure 1-4,the worker's resting heart rate and heart rate at work as well as age and weight information into formula, draw the average metabolic rate of all workers . compared with the average metabolic rate with different types of work, it could find that steel worker and piling rig worker is the hardest work in this survey,because they have to work in a environment that is directly exposed to sun,In addition The average metabolic rate of the handyman is the smallest, consistent with the results observed by the researchers, their labor intensity is relatively low, and it does not work with direct sunlight. The horizontal line in the figure is the average metabolic rate of all workers.

Table 2. Average heart rate of workers in different type of work and metabolic rate

JOBS	Resting average HR (bpm)	Working average HR (bpm)	Working-resting (bpm)	Minimum average HR (bpm)	Maximum average HR (bpm)	Average Metabolic (W/m^2)
Outdoor scaffolding workers	82.74	103.35	20.61	74.29	128.86	160.93
scaffolding workers inside building	79.49	96.42	16.94	69.00	122.40	128.97
carpenter	85.32	106.77	21.45	73.38	135.31	159.36
porters	82.38	101.55	19.16	74.50	131.50	139.54
handymen	77.21	87.86	10.65	67.25	109.00	98.13
plumber	84.69	101.44	16.76	74.40	123.00	132.65
plasterer	87.99	101.98	14.00	74.00	141.75	127.16
piling rig worker	100.57	126.60	26.03	90.50	150.50	201.10

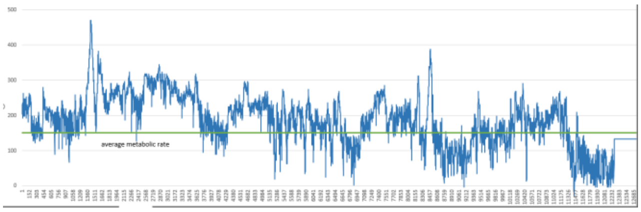

Figure 1. Average metabolic rate of steel workers

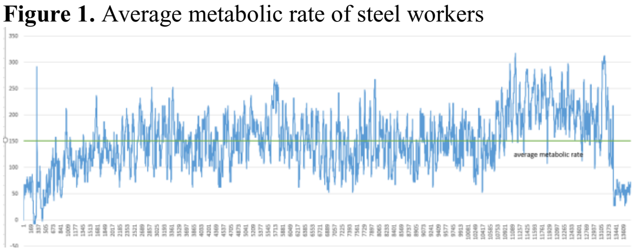

Figure 2. Average metabolic rate of carpenter

Figure 3. Average metabolic rate of outdoor scaffolding workers

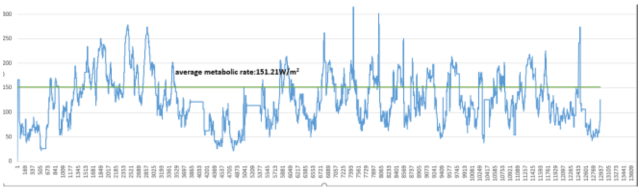

Figure 4. Average metabolic rate of porters

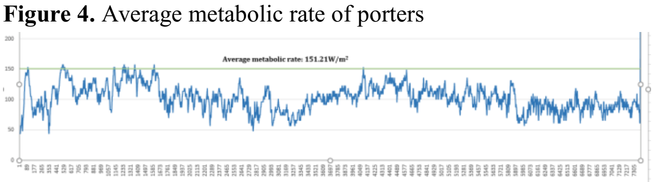

Figure 5. Average metabolic rate of handymen

Table3. Significance level of the average metabolic rate of workers with different types

	1	2	3	4	5	6	7	8
1		*0.004*	*0.000*	0.030	0.870	*0.000*	*0.000*	0.052
2			0.110	0.657	0.459	*0.006*	0.045	0.497
3				0.067	0.043	0.048	0.509	0.380
4					0.764	*0.004*	0.029	0.831
5						*0.003*	0.019	0.921
6							0.122	*0.003*
7								0.016
8								

1- handymen ; 2-porters ; 3-carpenter ; 4-plumber ; 5-plasterer ; 6- piling rig worker ; 7-Outdoor scaffolding workers; 8- scaffolding workers inside building

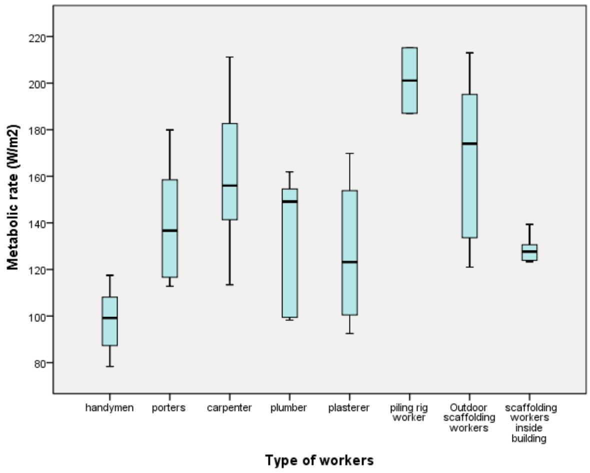

Figure 6. Boxplot of the average metabolic rate of workers with different types

It can be found from Table 3 that there is a significant difference in the average metabolic rate between the handyman and the porter, piling rig worker, and Outdoor scaffolding workers ($P<0.005$). Due to the low labor intensity and the fact that most of the handymen are not working in direct sunlight,the average metabolic rate of the handyman is significantly lower than that of other workers. On the contrary, the average metabolic rate of the digging well was significantly higher than that of other workers ($P<0.01$)，which due to their high labor intensity and the direct sunlight in their workplace.

4 Discussion and Conclusions

In 2018, Chongqing issued "high temperature red warning" signals many times, and temperatures in many districts and counties reached 40.0°C or above.Workers are in a very poor thermal environment, both in China and in international standards, it is very likely to cause the worker's health hazard and generate heat damage. although there are significant individual differences in metabolic rate among workers，it is found that the trend of heart rate and metabolic rate of workers in the same type of work is similar. and that the average metabolic rate of workers with different jobs is obviously distinctive. Different types of work may face different risks of thermal damage. Such as steel workers, piling rig workers, and scaffolding workers who work outside and who have relatively high labor intensity should receive more comprehensive thermal protection measures. It is recommended to wear relevant physiological parameter monitoring instruments to protect workers' safety in case of thermal disease. Adjusting of workers may be hampered by certain restrictions on a construction site. On the other hand ,such behaviours as working on a scaffolding or plastering in a poorly lit space would affect the worker's frequency of drinking or resting. The impact of workplace space constraints on self-regulation of workers is also a potential research direction.

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