



MEASUREMENT SURVEY ON CONSTRUCTION LABOUR PRODUCTIVITY UNDER HEAT STRESS DURING THE COOL SEASON IN CAMBODIA

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Abstract : Global warming is causing a rise in severe and prolonged heat stress, posing a significant occupational risk to construction workers, potentially leading to health issues and decreased productivity. Cambodia's cool season heat stress has not been previously studied, which is why this study aims to do a measurement survey of its impact on construction labour productivity and health during this challenging time. To accomplish this goal, repeated measures methodology and descriptive statistics were implemented. Demographic, physiological, environmental, psychometric, and construction labour productivity variables were observed and recorded. The means and standard deviation of various variables have been assessed using descriptive statistics. The results showed that less heat strain was felt by the workforce in the morning session compared to the afternoon session (81.61% of the morning session's workers reported no heat strain, while 0.95% reported moderate heat strain). Workers were subjected to greater heat strain when the WBGT or heat stress indicator hit 32.93°C between 13:00 and 14:00. Additionally, the CLP level was quite comparable in both shifts at roughly 60%. Although the CLP was high from 13:00 to 14:00, workers had greater heat exhaustion. Workers are in good health with heart rates (low work intensity accounted for 71.10%). Overall, the new findings of this study suggest that Cambodia faces perceptual strain under heat stress during the cool season, requiring construction managers to identify and mitigate risks of heat stress on workers' psychometrics factors.

Index Terms – Construction Labour Productivity, Cool Season, Heat Stress, Perceptual Strain Index (PeSI), WBGT, Work Intensity

I. INTRODUCTION

One of the most prominent environmental issues of the twenty-first century is global climate change, which has the potential to have an impact on human health both directly and indirectly (Moda et al. 2019). Moreover, the frequency of high temperatures in outdoor work situations is rising due to global warming. The increased risk of heat stress from this temperature rise, as a result of among workers, might directly affect their physical health and productivity (Szewczyk et al. 2021).

In recent years, the researcher has studied the impact of heat stress on workers' productivity in the Construction sector. Langkulsen et al. (2010) conducted a study in Thailand to investigate the effect of heat stress on work productivity in the construction industry. The study found that heat stress can lead to a decrease in productivity in construction workers, with the magnitude of the decrease being dependent on the severity of the heat stress. Somanathan et al. (2021) conducted a meta-analysis of studies on heat stress and worker productivity. The study found that heat stress can lead to a decrease in productivity in workers, with the magnitude of the decrease being dependent on the type of work being performed, the worker's fitness level, and the availability of cooling measures. The previous study's findings also have implications for other countries in Southeast Asia with hot and humid climates. For example, a study by Somanathan et al. (2021) found that for every 1°C increase in temperature, a hot and humid country like India has a 2% loss of productivity. The previous study's findings are consistent with those of other studies on the impact of heat stress on worker productivity. For example, a study by Yi and Chan (2017) found that a 1°C increase in temperature was associated with a 0.33% decrease in construction labour productivity (CLP) in Hong Kong. Similarly, a study by Li et al. (2016) found that a 1°C increase in temperature was associated with a 0.57% decrease in CLP in Beijing.

Here are some literature reviews that find the contrast that heat stress has no serious effect on construction labour productivity: A study by Mohamed and Srinavin (2005) found that there was no significant difference in productivity between workers who were exposed to heat stress and those who were not. The study was conducted in Thailand, and the researchers found that productivity was more likely to be affected by other factors, such as the type of work being performed and the availability of shade and water. The research conducted by Chan et al. (2012) likewise revealed that there was no notable impact of heat stress on worker productivity. The study was conducted in Hong Kong, and the researchers found that productivity was more likely to be affected by other factors, such as the age of the workers and the amount of rest they were allowed. A study by Lee et al. (2018) found that heat stress could decrease a small percentage of productivity in some regions and increase productivity in some small

cases. The study was conducted in South Korea, and the researchers found that workers who were exposed to heat stress were more likely to work harder and take fewer breaks.

There have been conflicting findings in the literature study mentioned above about how heat stress affects worker productivity in the construction industry. Some studies have found that heat stress can lead to a decrease in productivity, while others have found no significant effect or even an increase in productivity. The findings of the literature review suggest that the impact of heat stress on labour productivity is complex and depends on several factors. It is crucial to consider all of these factors when assessing the impact of heat stress on productivity in the construction sector. This study hypothesizes that heat stress will have a negative impact on CLP in Cambodia even in the cool season. The study will test the hypothesis by conducting an on-site measurement survey on construction workers in Cambodia.

There is limited data from measurement surveys on the construction workers in Cambodia, which is located in a tropical region (hot and humid) with an average temperature between 24.13°C and 32.54°C for the last 12 years (ClimateCHIP, 2023). Construction workers in Cambodia may be threatened by heat stress and it could have a negative impact on productivity. Therefore, the goals of the study are to do a measurement survey on workers' productivity due to heat stress and to disseminate knowledge about this measurement in the construction sector.

II. RESEARCH METHODOLOGY

2.1 Experimental Design

The effects of heat stress on construction labour productivity were examined using a repeated measures methodology. How does heat stress affect construction labour productivity in Cambodia during the cool season?

Twenty healthy rebar workers from Phnom Penh, Cambodia, and 5 building sites participated in the study. Workers were randomly assigned to the study ($n = 20$ participants). The age range of participants was 18-54 years old and male only. The period of data collection started from November 2022 to March 2023.

2.2 Experimental Preparation

In this study, demographic, environmental, physiological, psychometric and construction labour productivity data were gathered as the five main factors. The exclusive criteria were used to confirm that personal health issues would not affect the data's accuracy. The exclusive criteria include a worker with a health condition such as hypertension, diabetes, cardiovascular, neurological diseases, or symptoms of heat-related illness including confusion, drenching sweats, headaches, fainting, nausea, shortness of breath, or cramps (Wong et al. 2014). Demographic information, including age, height, weight, level of education, smoking habit, and alcohol-drinking habit, was collected before the working shift started. Psychometric data, including thermal sensation (TS) and rating of perceived exertion (RPE), were collected by asking questions to individual workers every 15 minutes. Environmental data included ambient temperature, relative humidity, and globe temperature. Physiological data including heart rate was used to monitor the real-time heart rate of each participant. The study was approved by the National Ethic Committee for Health Research in Cambodia (NECHR) (reference number 037 NECHR). Before taking part in the study, each subject gave their written informed consent.

2.3 Data Collection

2.3.1 Demographic Data

The demographic data was obtained by asking questions 15 minutes before the beginning of labour. The questions included name, age, role on the site, age, level of education, smoking, alcohol consumption, height, weight, health-related questions, and symptoms of heat-related illness over hot and humid weather.

The demographic data of construction workers can vary by country and by the nature of the construction work. In addition, the education level of construction workers in Cambodia varies. Some workers have only primary school education, while others have completed high school or even college. Some workers have only a few years of experience, while others have worked in the construction industry for many years.

2.3.2 Environmental Parameters

In this study, the environmental data was monitored using a heat stress monitor (QuesTemp 36, USA). The recording parameters include natural wet bulb temperature, dry bulb temperature, relative humidity, and globe temperature. Wet Bulb Globe Temperature (WBGT) is used to assess the risk of heat stress. It can be calculated using (Eq. 2.1) (Budd, 2008, Parsons, 2006).

$$WBGT_{\text{outdoor}} = 0.7NWB + 0.2GT + 0.1DB \quad (2.1)$$

Where: WBGT is Wet bulb globe temperature index, NWB is Natural wet-bulb temperature, DB is Dry-bulb temperature, and GT is Globe Temperature.

2.3.3 Psychometric Parameters

There are two parameters such as thermal sensation (TS) and rating of perceived exertion (RPE) involved in the psychometric section. TS was assessed using a 7-point scale, with 7 representing "neutral and comfortable" and 13 representing "intolerably hot" (Gagge et al. 1967). In addition, the participants were instructed to rate their thermal sensation at the end of each 15 minutes using a questionnaire. RPE is a subjective measurement of how hard a person feels they are working using the Borg RPE scale, a 10-point scale with 0 representing "resting" and 10 representing "maximal exertion" (Borg, 1970). Participants were instructed to evaluate their RPE at the end of each 15 minutes using a questionnaire.

Perceptual strain index (PeSI) was an index used to measure heat strain and assess the health risks associated with heat exposure for workers. PeSI is calculated using (Eq. 2.2) (Tikuisis et al. 2002). This index was separated into five score ranges. PeSI values ranging from 0 to 2 indicate "little or no heat strain", 3 to 4 imply "low heat strain", 5 to 6 "represent moderate heat strain", 7 to 8 reveal "strong heat strain", and 9 to 10 illustrate "very high heat strain".

$$PeSI = 5 \times [(TS - 7)/6] + 5 \times (RPE/10) \quad (2.2)$$

2.3.4 Construction Labour Productivity

The percentage of direct working time has been recommended as a useful metric for assessing the productivity of construction labour in several studies (Liou and Borcherdig, 1986).

In this study, AACE International (Association for the Advancement of Cost Engineering) was used to estimate labour productivity. Regarding the method proposed by AACE International, work activities were divided into three categories as shown in Table 1. The activity is categorized into direct, indirect, and nonproductive time. The time spent on tasks that directly support the production of a product or service is referred to as a "direct task". The time spent on tasks that are not directly linked to the production of a product or service but are important for the efficient operation of the workplace is known as an indirect task. Non-productive time is the time spent on activities that do not contribute to the production of the product or service and are not necessary for the smooth running of the workplace. To collect construction labour productivity, each observer investigates and records the participant's activity every minute.

Table 1: Classification of direct, indirect, and non-productive work tasks

A. Direct Tasks	
A-1	Use wrenches for connecting, cutting, bending, and adjusting steel reinforcement bars
A-2	Reinforcing steel bar modifications
A-3	Place reinforcing steel bars
A-4	Carry reinforcing steel bars
A-5	Use meter sticks for measurements
A-6	Bending
B. Indirect Tasks	
B-1	Go in the direction of the tools, equipment, and supplies
B-2	Hold off until the materials are delivered
B-3	To know the work, read a list of materials
B-4	Discuss the tasks with the foreman and the other employees
B-5	Take materials
C. Non-Productive Activities	
C-1	Workers or machines, or both, as a result of a work halt owing to whatever reason
C-2	Talk on the phone, smoke, drink, sit, and use the restroom.

2.3.5 Physiological Parameters

The heart rate was measured using a Polar H10 heart rate sensor. The sensor was wet with water to improve the conductivity of the electrodes. The sensor was then connected to a smartphone using Bluetooth. The Polar H10 heart rate sensor is a chest-worn heart rate monitor that measures heart rate using an electrocardiogram (ECG). The heart rate sensor was connected to a smartphone via Bluetooth to monitor heart rate. (Eq. 2.3) can be used to calculate HRmax (Fox and Naughton, 1972). The percentage of heart rate maximum (%HRmax) was calculated using (Eq. 2.4). A Heart rate sensor is worn around the chest of workers at the start of working hours. Moreover, it is released from the workers at the end of working hours.

The Body Mass Index (BMI) plays a significant role in identifying weight categories that may contribute to potential health issues. The following BMI classifications are provided by the World Health Organization (WHO): Underweight (BMI < 18.5), Normal weight: (BMI 18.5–24.9), Overweight: (BMI 25.0–29.9), Obesity class I: (BMI 30.0–34.9), Obesity class II: (BMI 35.0–39.9), Obesity class III: (BMI ≥ 40.0) (WHO 2010). BMI is calculated by using (Eq. 2.5) (Donoghue and Bates, 2000).

$$\text{HRmax} = 220 - \text{Age} \quad (2.3)$$

$$\% \text{HRmax} = \text{HR} / \text{HRmax} \quad (2.4)$$

$$\text{BMI} = \text{Weight} / \text{Height}^2 \quad (2.5)$$

III. RESULT AND DISCUSSION

3.1 Demographic Parameters

As a result of the BMI in this study in Table 2, the average was 22.66 kg/m² which falls within the normal weight range according to the World Health Organization's BMI categories (WHO, 2010). 5% of the workers were underweight, 70% were normal weight, and 25% were overweight. In this study, the participants had an average age of 30.25 years old. The study's participants had a range of educational backgrounds. 5% were illiterate, 45% had completed primary school, 40% had completed secondary school, 10% had completed high school, and 0% had completed university. In terms of smoking and alcohol consumption, 40% of the participants were smokers and 80% reported drinking alcohol.

Table 2: Demographic information of workers

All participants (n = 20)	Mean ± SD	Range
Age (years old)	30.25 ± 12.22	18-54
Height(m)	1.65 ± 0.06	1.56-1.75
Weight(kg)	60.98 ± 9.09	49.1-78.8

BMI (kg/m ²)	22.26 ± 2.6	17.67-26.63
Good BMI		18.5-24.9

3.2 Environmental Parameters

The result from Table 3 showed that the lowest value of 20.55°C was recorded between 7:00 and 8:00, while the highest value of 32.93°C was recorded between 13:00 and 14:00. The hourly WBGT changed, rising during the morning shift from 7:00 to 11:00 and declining during the afternoon shift from 13:00 to 17:00. Overall, WBGT levels were often highest at 13:00 compared to other times.

Table 3: Descriptive summary of WBGT throughout morning and afternoon shifts

Time	WBGT(°C)	
	Mean ± SD	Range
7:00-8:00	24.74 ± 2.59	20.55-30.01
8:00-9:00	25.82 ± 3.10	21.32-32.20
9:00-10:00	26.82 ± 2.85	22.36-31.77
10:00-11:00	27.68 ± 2.64	23.98-31.98
13:00-14:00	29.07 ± 2.11	25.66-32.93
14:00-15:00	28.53 ± 1.90	25.41-31.81
15:00-16:00	28.23 ± 1.97	23.93-31.77
16:00-17:00	27.35 ± 2.31	22.84-30.60

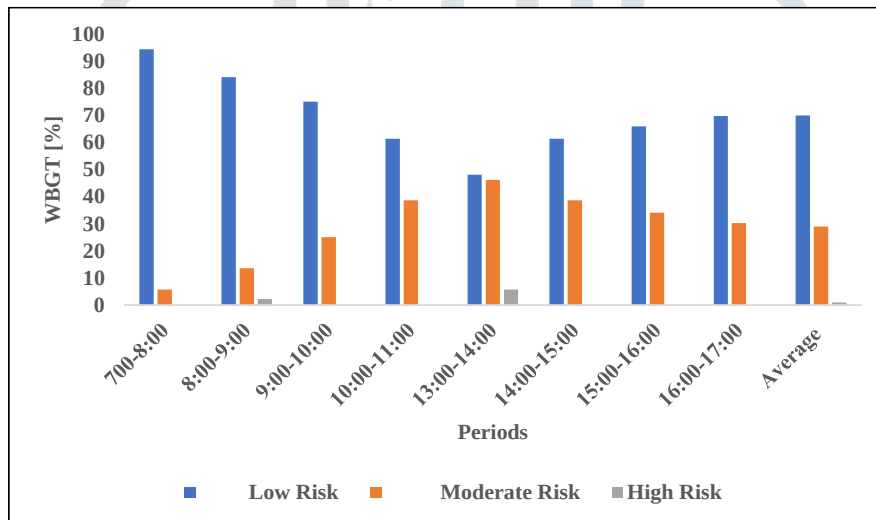


Figure 1: The percentage of level risk of WBGT with times

According to the Department of Army, they claimed the level risk of WBGT as follows three categories: low risk (WBGT < 29.3°C), moderate risk (29.4°C < WBGT < 32.1°C), high risk (WBGT > 32.1°C) (MED and PAM, 2022). The hourly distribution showed that low-risk, moderate-risk, and high-risk accounted for 69.98%, 29.01%, and 1.01% in average of the day, respectively as shown in Fig. 1

3.3 Psychometric Parameters

The results from Fig. 2 show that the percentage of workers who experienced no heat strain was highest in the morning (7:00-8:00) and lowest in the afternoon (13:00-14:00). The percentage of workers who experienced low heat strain was highest in the afternoon (13:00-14:00) and lowest in the morning (7:00-8:00). The percentage of workers who experienced moderate heat strain was highest in the afternoon (13:00-14:00) and lowest in the morning (7:00-8:00).

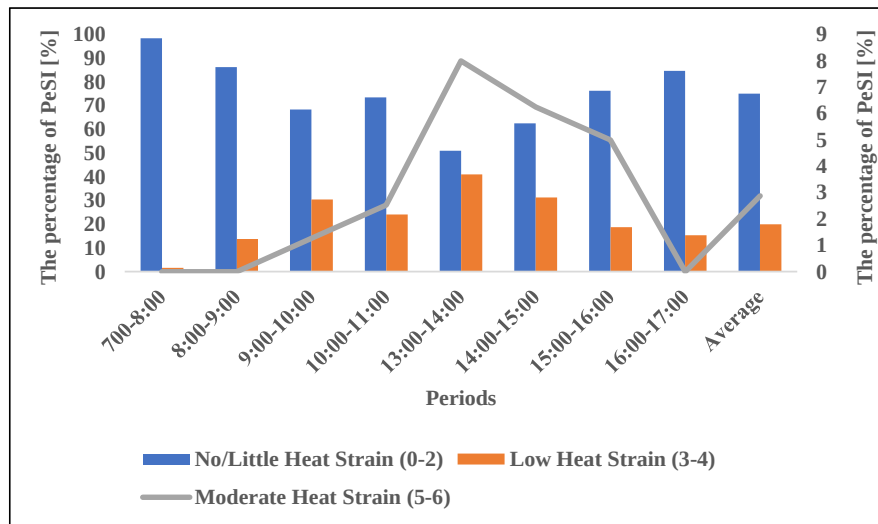


Figure 2: The percentage of the level of perceptual strain index (PeSI) with times

3.4 Perceptual Strain Index (PeSI) with Wet Bulb Globe Temperature (WBGT)

Table 4 shows the level of risk of heat stress associated with different values of WBGT. The table categorizes WBGT levels into three categories: High, Moderate, and Low. These values indicate the risk levels associated with different WBGT categories, with higher values indicating higher levels of heat stress and potential health risks. The results show that the high-risk of heat stress is high when WBGT is greater than 32.1°C, and the mean of PeSI is 3.39 (moderate heat strain). For moderate risk of heat stress, the mean of PeSI is 2.27 (no or little heat strain). For the low risk of heat stress, the mean of PeSI is 1.93 (no or little heat strain).

Table 4: Classification of Perceptual Strain Index (PeSI) based on WBGT risk level

WBGT(°C)	PeSI
High (WBGT>32.1)	3.39 ± 1.51
Moderate (29.4<WBGT<32.1)	2.27 ± 1.13
Low (WBGT<29.3)	1.93 ± 1.05

The results of the study suggest that workers were more likely to experience heat strain in the afternoon than in the morning in Fig. 1 and Fig. 2. The results of this study are consistent with the findings of Petruzzello et al. (2009), who confirmed that heat strain is the body's physiological response to heat stress and reflects how an active person interacts with their ambient environment. Gao et al. (2018) have also reviewed the evidence that heat strain is influenced by environmental temperature. They concluded that "the risk of heat strain is likely to increase with rising temperatures, particularly in hot and humid environments.

3.5 Construction Labour Productivity (CLP)

The result from Fig. 3 shows that the majority of working hours are dedicated to direct tasks (58.43%), followed by non-productive (25.27%), and indirect tasks (16.73%). The proportion of non-productive is nearly the half of direct tasks. The percentage of direct tasks drops marginally from 7:00 to 10:00 and dramatically from 10:00 to 11:00 during the morning work shift. From 13:00 to 17:00 (afternoon shift), the percentage of direct tasks slightly decreases. Importantly, both shifts had a level of CLP around 60%, similarly.

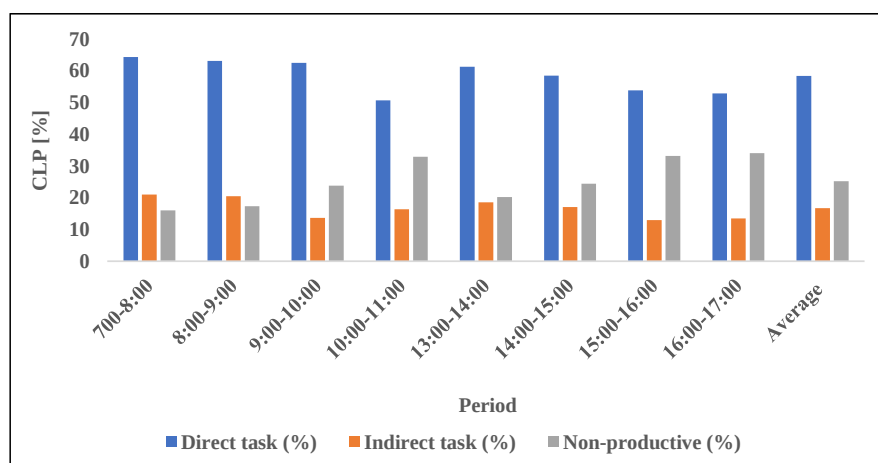


Figure 3: The percentage of construction labour productivity (CLP) with times

3.6 Perceptual Strain Index (PeSI) with Construction Labour Productivity (CLP)

According to the graph in Fig. 4, the highest percentage of no heat strain has the biggest CLP [%] in the morning shift (7:00-8:00). Furthermore, the highest percentage of moderate heat strain also has the high CLP [%] in the afternoon shift (13:00-14:00). The results shows that when the moderate heat strain slightly decreased, the CLP also slightly dropped in the afternoon session. During 13:00-14:00, worker spend their time on direct tasks and work hard under sunlight (WBGT can reach 32.93 °C). They get more heat strain, like feeling hot, increased body temperature, sweating, and thirst. Crucially, they cannot carry the steel bar without sockets because the steel bar stores the heat from the sunlight.

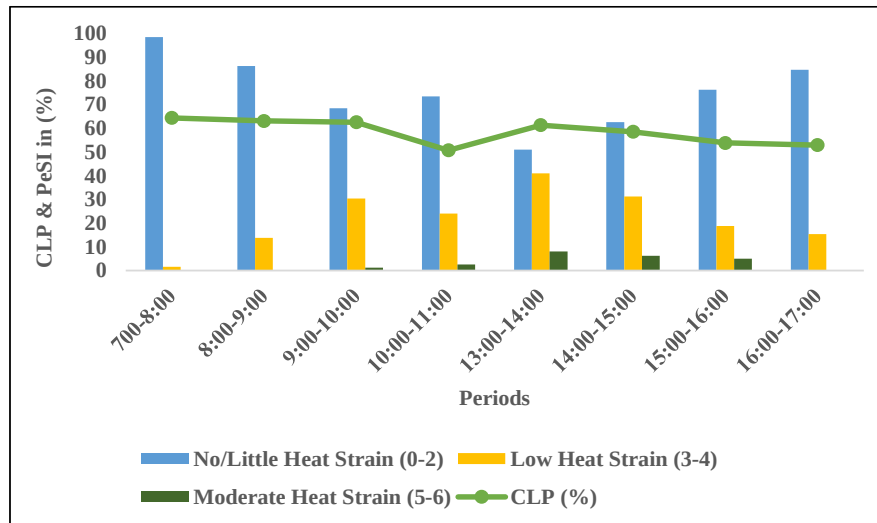


Figure 4: The percentage of construction labour productivity (CLP) and Perceptual Strain Index (PeSI) with times

3.7 Wet Bulb Globe Temperature (WBGT) with Construction Labour Productivity (CLP)

The graph in Fig. 5 illustrates that moderate and high risk of WBGT increased during 13:00-14:00, and CLP also increased at that time. There is one reason for this trend. After 11:00, workers take a break for two hours until 13:00.

During the break time, workers have lunch, energy drinks and sleep. So, when they get up at 13:00 and start working, they get energy more for work in the afternoon shift. That is why they can make the high CLP during 13:00-14:00 under the high risk of WBGT. The graph also shows that at the end of the work shift, CLP declines close to the end of the working shift because of tiredness and decreasing motivation in the work of workers. Crucially, there is no significantly different value of CLP in both shifts.

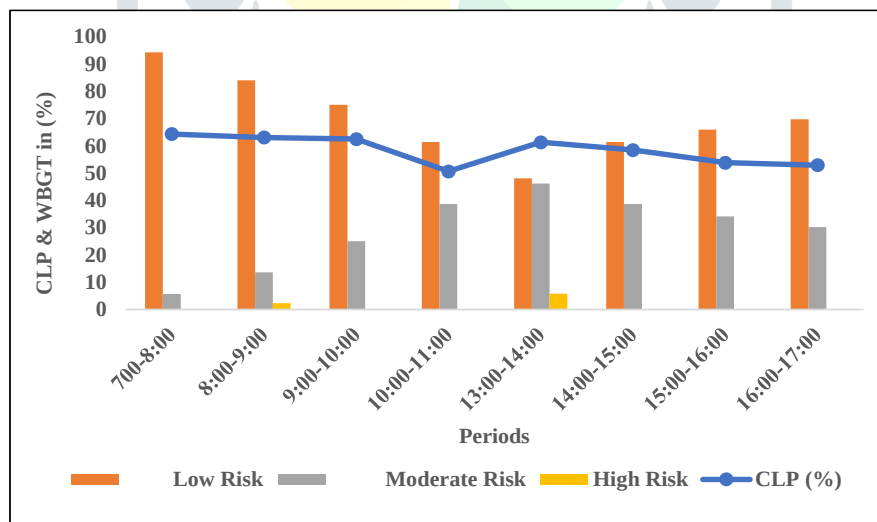


Figure 5: The percentage of construction labour productivity (CLP) and WBGT with times

3.8 Physiological Parameters

Heart rate (HR) is a physiological indicator of work intensity (Minard et al. 1971). In 1971, Minard et al. (1971) proposed a classification system for work intensity based on HR, dividing it into three groups: light (HR < 54% HR_{max}), moderate (HR < 69% HR_{max}), and high (HR > 70% HR_{max}). In 1998, the American College of Sports Medicine (ACSM) adopted this classification system and recommended it for use in occupational settings (Pollock et al. 1998).

Table 5: Descriptive summary of Heart rate throughout morning and afternoon shifts

Time	HR (bpm)	
	Mean $\pm$ SD	Range
7:00-8:00	92.48 $\pm$ 11.21	72-114
8:00-9:00	92.93 $\pm$ 10.75	71-113
9:00-10:00	91.08 $\pm$ 14.73	63-123
10:00-11:00	90.57 $\pm$ 13.01	64-127
13:00-14:00	93.43 $\pm$ 14.28	66-130
14:00-15:00	93.71 $\pm$ 14.68	60-128
15:00-16:00	95.96 $\pm$ 16.15	60-132
16:00-17:00	91.79 $\pm$ 13.24	61-116

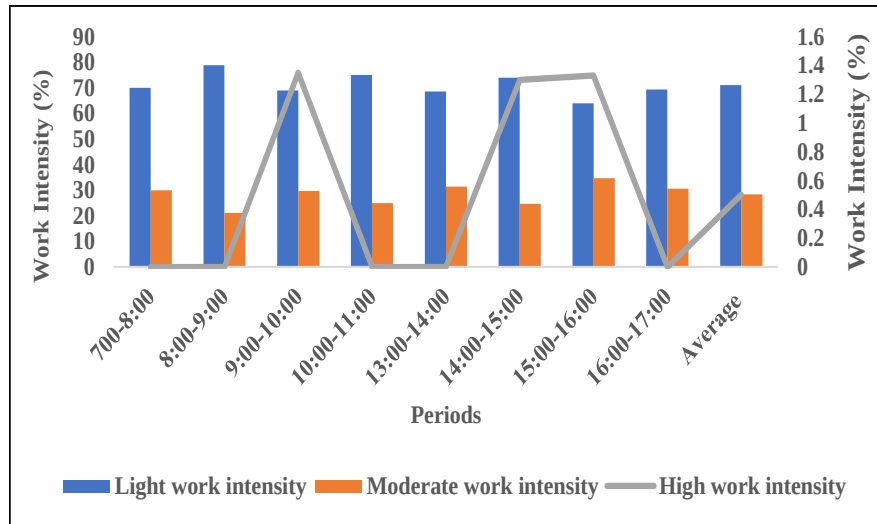


Figure 6: The percentage of level of work intensity with times

Table 5 shows the hourly heart rate fluctuated from around 91 to 96 bpm (They are within good HR). In particular, the values of HR were greater around 15:00 (14:00-15:00 and 15:00-16:00) than at other periods (7:00-11:00, 13:00-14:00, and 16:00-17:00). A good daily average heart rate during work is under 120 bpm (Minard et al. 1971). Based on World Health Organization (WHO), (1969), when a person's heart rate is higher than 161 bpm for a brief period, this means that person is under significant strain. Regarding to Du et al. (2018) found that hot temperature can lead to an accelerated heart rate. The average adult resting heart rate (HR) from the age range between 18 to 45 years old is believed to be greater or equal to 110 bpm. However, the values of HR in this study were lower than those recorded in previous research, suggesting that the workers were not engaged in highly-intense work.

The hourly distribution showed that low work intensity, moderate work intensity, and high work intensity accounted for 71.10%, 28.40%, and 0.50% of the average of the day, respectively as shown in Fig. 6.

Table 6 shows that there is a similarity in the average values of CLP, PeSI, and WBGT between the three work intensity categories. Such a difference is likely due to several factors, including the type of work being performed, the environmental conditions, and the individual's fitness level

Table 6: Classification of variables based on work intensity level

Work Intensity	CLP	WBGT	PeSI
High (HR > 70%HR _{max})	0.62 $\pm$ 0.30	27.98 $\pm$ 4.63	2.06 $\pm$ 0.38
Moderate (HR < 69%HR _{max})	0.67 $\pm$ 0.28	27.21 $\pm$ 2.54	1.99 $\pm$ 1.19
Light (HR < 54%HR _{max})	0.63 $\pm$ 0.27	27.32 $\pm$ 2.64	2.04 $\pm$ 1.06

IV. CONCLUSION

The key findings of this measurement survey are that in the morning session, workers experienced less heat strain than in the afternoon session (no heat strain in the morning accounted for 81.61% and moderate heat strain was only 0.95%). When WBGT or heat stress indicator reached 32.93°C during 13:00-14:00, workers are experienced more heat strain. Moreover, both shifts had a level of CLP is around 60%, very similar. However, workers got more heat strain with high CLP during 13:00-14:00.

The average worker's heart rate is between 91 and 96 bpm, less than 120 bpm. Therefore, workers are not exposed to heat stress. They are in good condition (low work intensity represents 71.10%).

Future studies should focus more on heat-related symptoms to mitigate the heat strain on workers and also improve construction labour productivity.

V. ACKNOWLEDGMENT

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