UNIVERSITY OF NAIROBI

FACULTY OF BUILT ENVIRONMENT & DESIGN

DEPARTMENT OF REAL ESTATE, CONSTRUCTION MANAGEMENT AND QUANTITY SURVEYING

ASSESSMENT OF HEAT STRESS EXPOSURE ON CONSTRUCTION WORKERS IN WARM AND HUMID ENVIRONMENTS

A Case Study of Mombasa County

SUBMITTED BY:

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(B53/81528/2015)

A RESEARCH PROJECT SUBMITTED IN PARTIAL FULFILLMENT FOR THE AWARD OF THE DEGREE OF MASTER OF ARTS IN CONSTRUCTION MANAGEMENT IN THE DEPARTMENT OF REAL ESTATE, CONSTRUCTION MANAGEMENT AND QUANTITY SURVEYING, FACULTY OF BUILT ENVIRONMENT AND DESIGN

FEBRUARY, 2022

DECLARATION

DECLARATION BY THE CANDIDATE

I, PHILLIP OTIENO GENO KOTENG, hereby declare that this research project is my original work and has not been presented for the award of a degree in any other University.

Signature………………………………………… Date 5.07.2022

DECLARATION BY THE SUPERVISOR

This research project has been submitted for examination with my approval as the University supervisor.

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DEDICATION

This work is dedicated to the Almighty God for giving me the gift of life and therefore the ability to undertake this study to its successful completion;

And to my loving parents, Mr. and Mrs. Geno Koteng for their inspiration, encouragement and support:

And to my wife, Eva Mshila for moral support and belief in my ability;

And my children, Russell and Jasmine, you give me the passion.

ABSTRACT

Construction workers are at high risk of heat stress, due to the demanding nature of their work and the high temperature work condition. Open field workers such as construction workers have to carry out physical works in warm and humid conditions hence they are more vulnerable to heat stress. The objectives of the study were: to assess occupational factors affecting construction workers that are related to heat stress on site during construction; to measure the heat levels of construction sites in warm and humid environment; and to assess heat stress risk on construction workers using the Wet Bulb Globe Thermometer (WBGT) index and Humidex Index. Construction workers were identified using stratified sampling in the 6 constituencies of Mombasa County. Field studies were conducted in January and February 2022 whereby 463 sampled construction workers were observed during construction work. Workers were classified into 6 job categories namely steel Reinforcement works, walling, form work construction, concreting, plumbing and electrical works and roofing works. The levels of exposure of construction workers to direct sunlight was recorded, perceived exertion recorded using the Borg CR10 perceived exertion scale and workload was classified based on the ACGIH workload classification. Majority of workers who were unskilled (67%) and undertaking Concreting works (heavy work) and Steel reinforcement jobs (moderate work) were at high risk of heat stress based on their occupational activities. Both the WBGT and Humidex index used to assess the heat stress risk found out that construction workers exposed to the open sun and working between 12pm and 2pm were at the highest risk of heat stress followed by 10am-12pm and 2pm-4pm time periods. Construction work carried out between 10am-12pm and 2pm-4pm presented similar high risk environmental conditions felt by construction workers. Work-ability (productivity) levels were significantly reduced by 37% for light works, 62% for moderate works and 72% for heavy works between 12pm and 2pm. It was further noted that temperatures on construction sites could reach higher levels than the reported meteorological data. A One Way ANOVA test was performed on the environmental data collected for hypothesis testing. At p=0.00, using a Significance level $\boldsymbol{\alpha} = 0.05$, the null hypothesis was rejected. Construction managers and contractors are therefore recommended to measure the levels of WBGT on construction sites in warm and humid environments and issue alerts to construction workers working in the open environment to protect them from the likelihood of heat stress. Provision of shaded rest areas on site, worker rotation and flexible working hours were also to be adopted. It was concluded that the findings in this study should be adopted by stakeholders such as National Construction

Authority (NCA), and the Directorate of Occupational Safety & Health Services (DOSHS) in the development of heat exposure guidelines for construction workers in hot and humid environments in Kenya. Lastly, further studies can be undertaken by taking into account heat strain on construction workers in relation to heat stress studied in this research project. A similar study can also be undertaken for a longer period of time to give a better assessment because heat stress effects may appear later in the long-term.

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LIST OF ABREVIATIONS AND ACRONYMS

ILO – International Labour Organization
PPE – Personal Protective Equipment
NCA – National construction Authority
WMO – World Meteorological Organization
KMD – Kenya Meteorological Department
API – Air pollution Index
PSI – Physiological Strain Index
TWA – Time Weighted Average
WBGT – Wet Bulb Globe Temperature
WBGT$_{\mathbf{eff}}$ – Effective Wet Bulb Globe Temperature
GDP – Gross Domestic Product
NIOSH – National Institute for Occupational Safety and Health
MRT – Mean Radiant Temperature
CCOHS – Canadian Centre for Occupational Health and Safety
OSHA – Occupational Safety and Health Administration
ISO – International Organization for Standardization
ACGIH – The American Conference of Governmental Industrial Hygienists
CAF – Clothing Adjustment Factor
TLV – Threshold Limit Values
AL – Action Limit
HRI – Heart Rate Impairment
UAE – United Arab Emirates

LIST OF SYMBOLS

Symbol	**Term**	**Units**
Tpwb	Psychrometric wet-bulb temperature	°C, °F
Twg	Wet globe temperature	°C, °F
Va	Air velocity	m·s-1, fpm
W	Work	kcal·h-1
Σ	Stefan-Bolzmann constant	$Wm^{-2}K^{-4}$
mmHg	Pressure in millimeters of mercury	MmHg
Ta	Ambient air dry-bulb temperature	°C, °F
Tadb	Ambient dry-bulb temperature, adjusted for solar radiation	°C, °F
Tcr	Body core temperature	°C, °F
Tdp	Dew point temperature	°C, °F
Tg	Black globe temperature	°C, °F
Tnwb	Natural wet-bulb temperature	°C, °F
To	Operative temperature	°C, °F
Tr	Radiant temperature	°C, °F
M_r	Mean radiant temperature	°C, °F

CHAPTER ONE

INTRODUCTION

1.1 Background of the study

In 2019 the International Labour Organisation (ILO) stated that millions of workers across the world work under intensive heat. For most workers, intensive heat is likely to reduce their ability to work at optimum levels and affect their health. The phenomenon of heat stress refers to excess heat that cannot be borne by the body without being physiologically impaired. This excess body heat is usually generated by physical activities and heat from the environment the person is in. The most affected occupation by heat stress from the natural environment are mostly workers who work outdoors in the open sun such as people involved in agriculture and construction sites (International Labour Organisation, 2019).

Workers ability to work at optimum levels is a significant measure of production for those workers who work under intensive conditions and environments such as construction sites. Doloi et al. (2012) identified that reduction in construction workers working ability was one of the main reasons for the delays experienced by projects in construction. Shehata & El-Gohary (2012) noted that with proper management of workers, construction projects could yield savings in cost and time taken for construction. In warm and humid climates, excessive heat stress on construction workers is one of the aspects that influences work performance and how the overall project is likely to perform. The aim is to enable construction site workers to work at their optimum in these warm and humid climates. This can be done by designing a work-rest schedule that increases the amount of time construction workers are productive in a warm and humid environment. Environments that are warm and humid are likely to make construction workers more uncomfortable compared to environments that are warm and dry, where the heat stress is intensified by Personal Protective Clothing (PPE) and heavy workload among other factors (Zhang et al., 2014). Dunne et al. (2013) made an assessment about global labour capacity which they estimated has been reduced by environmental heat stress drastically in the hottest months. They predicted that in 2050, work-capacity will further be impacted by a reduction of 80%, therefore climates that are humid and warm climates poses severe limitations on individual work-capacity which is lost in the peak months of heat stress. Although productivity is also influenced by other factors other than heat stress, such as site organization, training and experience, skill-set and motivation, Grimm & Wagner (1974) also found out that construction workmanship could decline at relatively high temperatures. The research project therefore seeks to study the levels of heat stress in a warm and humid environment and how it affects construction workers during work at construction sites.

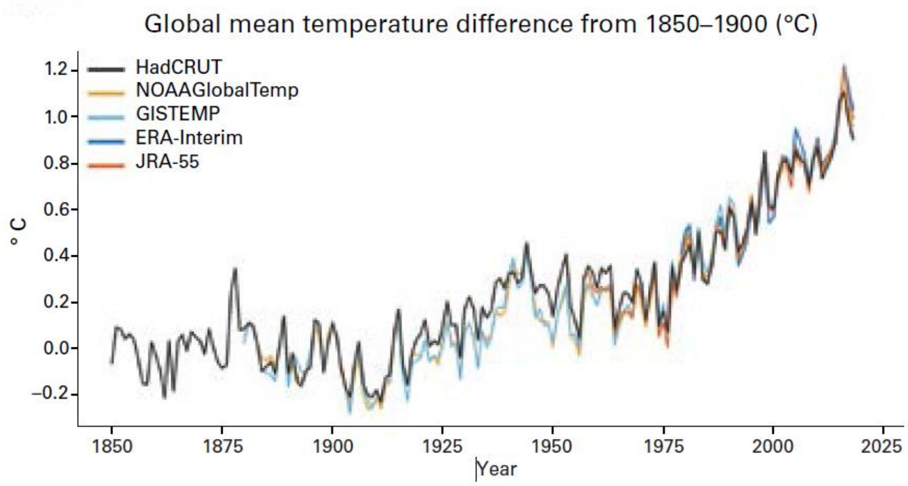
Construction worker are regarded as people who are at a high risk of experiencing heat stress because of high temperatures, the strenuous nature of their work, and climate change. Construction workers in Africa often experience long working hours with extremely high temperatures and access to shade and water can be minimal (Xiang et al., 2014). Productivity is considered a measure of the rate at which work is performed. Heat stress can have physiological effects on workers thus reducing their work-rate leading reduction in work enthusiasm, increased heat illness, incident rate, and even death (Yi & Chan, 2014). International Labour Organisation (2019) noted that temperatures exceeding 39°C can kill. ILO further noted that even in cases that do not experience fatalities, high temperature can make workers stranded without being able to work or have the ability to work at slower rates. Older individuals have lower physiological resistance than other groups due to their susceptibility to suffer from heat stress at significantly low temperatures.

It is estimated by the ILO that by 2030, 2% of the entire working-hours will be lost yearly worldwide. The reasons being that workers will find it extremely hot and therefore impossible to work at certain instances or workers will have no option but to work at reduced pace. Western Africa may have a 5% productivity reduction by the year 2030 (International Labour Organisation, 2019). The effects of the rise in global temperatures have different effects across various industries. Jobs that involve working in the open sun with high physical exertion levels are mostly affected by the rise of heat levels. Construction workers and those in the agriculture sector working in the open are expected to be severely affected (ILO, 2019). Global construction work-hours lost to heat stress was at 6 per cent in 1995. It is expected that global work-hours will experience a reduction of 19% by the year 2030 (ILO, 2019). Results conducted on healthy and adapted individuals undertaking high physical activities at high temperatures and documented under long term exposure indicate adverse reactions (Grimm & Wagner, 1974).

1.1.1 Global Warming and Heat Stress

Global warming is associated with severe and recurrent heat waves, and therefore vulnerable persons such as construction workers may end up with serious consequences. Excessive heat stress can affect an individual’s physiological ability. This can result into low productivity, work injuries, and even fatalities (Yi & Chan, 2017). The warmest years in history were between 2015 and 2018 with the year 2018 being the hottest ever recorded in history (International Labour Organisation, 2019). Figure 1.1 below shows the increase in global mean temperatures as recorded by various global atmospheric data analysis systems. All systems indicate an increase in global mean temperature levels worldwide.

Figure 1.1: Global mean temperature from 1850 - 2019



Source: World Meteorological Organization (2019)

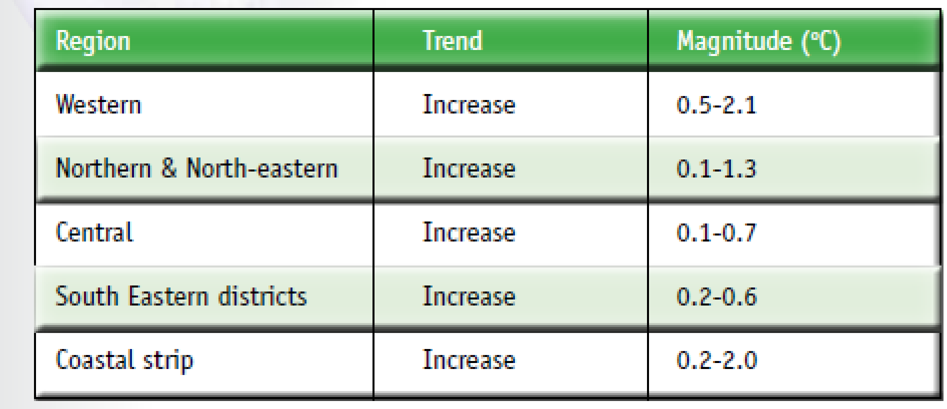
Events that have impacted the world because of global warming include the 2010 to 2012 drought in East Africa, which resulted in more than 250,000 fatalities. Mortalities in Pakistan and India reached about 4,100 due to heat waves in the year 2015 (International Labour Organisation, 2019). Global increase in temperatures which is caused by change in climate will make heat stress common. Projections of the climate patterns tend to lead towards rise in occurrences and the occasions of extremity of the observed weather. This is likely to result in loss of jobs. Excess heat experienced by construction workers may result in increased risks on a construction site. Extremities of these risks include heatstroke or loss of life. Urban heat Island phenomenon in congested areas will also increase the heat inside these areas further aggravating the risks faced by workers (ILO, 2019). Construction workers who are prone to prolonged exposure to intense heat and humidity are likely to reduce their interest and concentration, therefore increasing their irritability which may lead to illnesses that are heat related (Hancher & Abdi-Elkhalek, 1998).

Open field and Industry workers have to carry out physical works in hot and humid conditions. Hence they are vulnerable to heat stress. Assessment of heat stress is a complex process because it is related to both physiological and psychological stress. Physiological heat strain depends on the exposure time and the degree of time of maintaining a core body-temperature. (Yi & Chan, 2014). Globally, about 30 workers lost their lives in the United States from illnesses associated with injuries from heat between the years of 2003 and 2012 (Occupational Safety and Health Admin., 2013). The Center Construction Research and Training in the United States which compiled data on the mortalities of construction workers, indicated that conditions related to heat resulted in the death of 17 construction workers. (National Safety Council as cited by Yi & Chan, 2017). Construction workers undertaking scaffolding, structural reinforcement bar fixing, concreting works and construction of formwork are considered susceptible to heat stress. Economically heat stress is increasingly becoming a challenge to economic activity. Businesses ability to operate during the hottest hours is reduced and it can be costly to adapt to these new conditions (ILO, 2019).

1.1.2 Heat on the Coastal Strip of Kenya

In retrospect, early 1960’s saw Kenya generally experiencing increased temperatures over many areas. There is a depiction of an increasing trend in maximum temperatures in areas near large water bodies and in particular the coastal strip since the early 1960s (Government of Kenya, 2010). Figure 1.2 shows the maximum temperature trend which has increased by 0.2-2.0°C since 1960’s.This is a significant increase in temperature over such a period.

Figure 1.2: Maximum Temperature trend from 1960

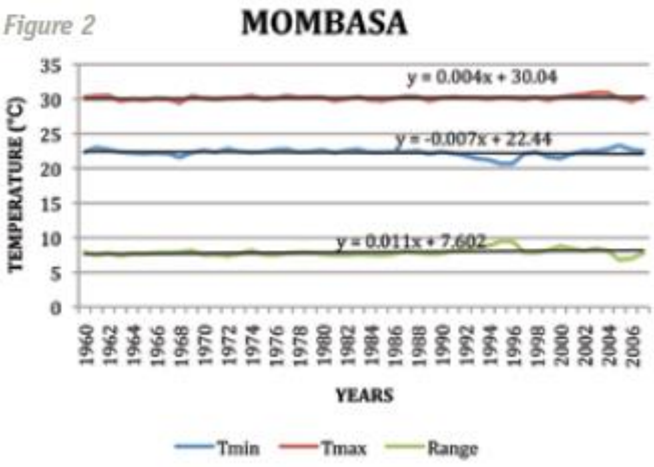


Region	Trend	Magnitude (°C)
Western	Increase	0.5-2.1
Northern & North-eastern	Increase	0.1-1.3
Central	Increase	0.1-0.7
South Eastern districts	Increase	0.2-0.6
Coastal strip	Increase	0.2-2.0

Source: Government of Kenya (2010)

Consequently, it is evident that there is an increase in the diurnal temperature range over Coastal line as a result of the days becoming much hotter while the nights and early morning temperatures have either not changed or reduced by small margins compared to early 1960s (Government of Kenya, 2010). Those trends are depicted in Figures 1.3 below

Figure 1.3: Temperature trend in Mombasa from 1960 to 2005



Source: Government of Kenya (2010)

Asefi-Najafabady et al. (2018) used simulations from high resolution Community Earth system Model(CESM) to study the effects of climate change and noted that the highest increase in heat stress days will occur in some parts of Kenya, Democratic Republic of Congo and Uganda. For example, dangerous heat is experienced by more than seventy million individuals in Uganda and Kenya for about 20 to 25 days in a year. According to the study, in 2090, the dangerous heat could be around 125 days of the year (University of Virginia, 2018). Reduction in work-rate for workers has an association with external outdoor temperatures above 24°C to 26°C. At 33 to 34°C, workers loose 50 per cent of their work capacity while operating at moderate intensity (International Labour Organisation, 2019). Acharya et al. (2018) noted that heat strain experienced by workers could be mitigated by periods of rest. According to Acharya et al. (2018) who reviewed literature on heat stress on construction workers noted that Yi and Chan (2014) estimated the probability distribution of physiological and behavioral conditions such blood pressure, heart rate, smoking habits and percentage of body fat using the Monte Carlo simulation. Yi and Chan (2014) also studied environmental conditions such as:

- WBGT, and
- Air pollution Index (API) of reinforcemnt bar construction workers

The study was conducted to calculate the optimal rest schedule. The study showed that after 120 minutes of work on a WBGT at 28.9 ° C ± 1.3 ° C, a 15 minute break was optimal for the worker. They recommended a slight increase in breaks and shorter working hours. To measure recovery from heat stress, a physiologic strain index (PSI) based on heart rate and core body temperature was measured in 19 outdoor reinforced workers.The study found that;

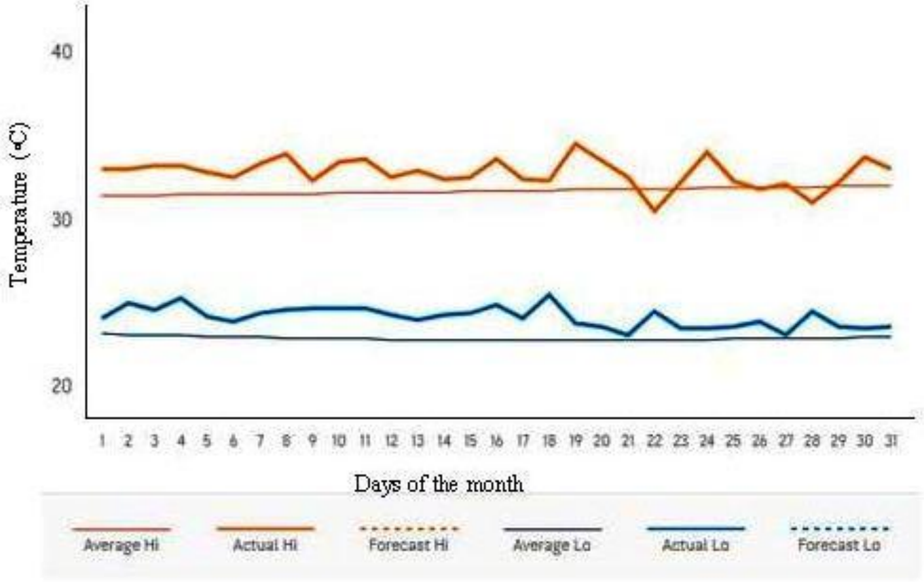
- 94% of the recovery occurred within 40 minutes of rest
- 84% of the recovery occurred within 20 minutes of rest
- 58% of the recovery occurred within 5 minutes of rest

The construction workers in the study were allowed to work to exhaustion (Chan et al, 2012) as cited in (Acharya et al, 2018). Furthermore SteveRowlinson & Jia (2015), implored the use of Time-Weighted Average (TWA) in the recovery time of construction workers undertaking heavy workload. The study found that;

- At 28.5°C WBGT, working for 120 minutes required a 5 minute break
- At 28.9°C WBGT, working for 90 minutes required a 10 minute break
- At 29.7°C WBGT, working for 60 minutes required a 15 minute break
- At 31.6°C WBGT and above, work at Self pace

With temperatures in Mombasa ranging between 31°C to 36 °C in the months January and March 2019, it may be impossible to work at self pace as recommended by Yi and Chan (2012) above for these 3 months. A more elaborate work rest schedule needs to be created to ensure construction projects in hot and humid environments meet the estimated completion period and costs through optimum productivity.

Figure 1.4: Highest and lowest temperatures in Mombasa in March 2019



Source: accuweather.com (2020)

1.2 Statement of the Problem

Thermal stress affects mostly the people who are exposed directly to the sun such as soldiers, athletes, farmers, travelers and often open field workers (Bell, 1981). Such open field workers include construction workers. This is because work is undertaken in the open without shading during their daily operations. In Kenya, construction workers who work under intensive heat include site workers undertaking steel reinforcement works and masonry works such as block laying and slab casting. Working under Intensive heat causes reduced workability and can cause accidents on site due to fatigue and loss of concentration. Heat stress is dangerous and can affect construction workers health and safety (Yi & Chan, 2017). A well-managed project requires construction managers to regulate the works of construction workers under intensive heat for optimum productivity.

Concreting works in Kenya are commonly done manually on site with only a few machines such us hoists and mixers generally to save on costs in residential projects. It is during concreting stage that construction workers are mostly prone to heat stress because the work is commonly done during the daytime and has to be completed by the end of the day. Sometimes construction workers have to endure strenuous activities such as carrying aggregates into the mixer for the entire day. Such strenuous construction work in hot and humid environments has resulted into heat exhaustion, accidents on-site and reduction in overall workability for construction workers. This therefore creates a need to investigate methods that would allow construction activities to progress at an efficient pace during the hottest months and reduce negative impacts on construction projects. In Kenya regulations that exist to prevent heat related illnesses in the construction industry are few even though these workers are among the ones who are likely to experience them.

Although fatalities and illnesses related to heat can be prevented with appropriate rest cycles, rehydration and shade, there aren't any guidelines in the construction industry in Kenya to ensure construction workers work at optimum levels during the hottest months in Mombasa. The situation is further aggraveted by construction workers wearing personal protective clothing such as coverals in these extremely hot and humid thermal environments. The National Construction Authority (NCA) requires all workers in a construction site to put on Personal Protective Equipment (PPE). These include: high visibility safety vests with reflective striping, safety boots, overalls and helmets. These safety apparel further increases heat generation on the body especially in hot and humid conditions such as those of Mombasa. Heat stress is more likely to affect jobs that require workers to wear personal protective equipment and other heavy clothing such as those of construction workers (International Labour Organisation, 2019). Rameezdeen & Elmualim (2017) noted that measurements taken in Hong Kong showed that air temperature inside a construction workers safety helmet was as high as 57°C while the environmental temperature was recorded at 33°C.

A number of variables are responsible for heat stress which includes temperature, clothing, humidity, wind, physical activities, shade and others. These variables vary tremendously depending on the worker's job and environment. Construction is a strenuous physical activity in nature and with the majority of the work being done under direct solar radiation puts workers at a high risk of heat stress. Heat stress can lead to fatigue and therefore affect construction workers mentally and physically. This translates to the increase in probability of accidents at construction sites, slower working rates and deaths. There is a need to assess heat stress on construction workers who currently work without assessment in the prevailing environmental conditions on a construction site.

1.3 Purpose of the Study

The global working population is facing occupational safety and health hazards due to climate change. If action is not taken, over 4 billion people living in regions that are warm and humid, will be affected by health and safety challenges and a reduction in work-ability in the 21st century (Kjellstrom et al., 2016). The damage resulting from unmitigated working conditions is the main cause of the observed heat stress is therefore a threat to the growth of the a nations real Gross Domestic Product (GDP) in Kenya and many other countries. The study sought to undertake assessment of construction workers in warm and humid environments in Mombasa Kenya where heat stress is most prevalent and work-ability in the open sun was at low levels.

The goal is to ensure that heat stress is mitigated and as a result work-ability will be improved, accidents will be reduced on site and there will be reduction to economic loses even for contractors. ILO estimated that economic losses around the globe because of heat stress in work-places were about US $280 billion in the year 1995. The figure is projected to vastly increase to US $2400 billion in the year 2030, with heat stress impacting lower middle and lower income countries including Kenya (ILO, 2019). The construction sector in Kenya plays a key role in the country's GDP and construction workers are the back-bone. GDP and construction workers are the back-bone. The study identified construction workers at construction sites in Mombasa where heat stress is most prevalent, examined the conditions and recommended strategies that could be used by a construction project manager to ensure that health and safety construction workers in warm and humid environments in Kenya. This will then translate to improved economic output in construction project in these environments.

1.4 Objectives of the study

The study sought to pursue the outlined main and specific objectives.

Main Objective

The Main Objective of the study was to assess the levels of heat stress on construction workers undertaking construction work at construction sites in warm and humid environments.

Specific Objectives

The specific objectives of the study were:

i. To assess occupational factors affecting construction workers that are related to heat stress on site during construction.
ii. To measure the heat levels of construction sites in a warm and humid environment.
iii. To assess heat stress risk levels on construction workers using the WBGT Index and Humidex Index.

1.5 Research Questions

The overall research question that the study aimed to answer was:

What are the levels of heat stress that construction workers working at construction sites in Mombasa County exposed to?

The specific research questions that guided the study were:

i. How do occupational factors (exposure to direct sunlight, perceived physical exertion and workload intensity) affect construction workers in construction sites in Mombasa County?

ii. What are the heat levels at construction sites in the warm and humid environment of Mombasa County?

iii. What are the heat stress risk levels on construction workers in Mombasa County when measured using the WBGT Index and Humidex Index?

1.6 Research Hypothesis

H_0: Construction worker are not significantly affected by the levels of heat stress in Mombasa during daytime work due to the warm and humid environmental conditions.

H_1: Construction workers are significantly affected by the levels of heat stress in Mombasa during daytime work due to the warm and humid environmental conditions.

1.7 Assumptions of the Study

1. Acclimatization will be considered as workers who have undertaken any construction work in the past two weeks prior to the study in Mombasa.

2. The study assumes construction work as labour intensive and a significant amount of its activities are generally undertaken in the open sun.

3. Some construction activities are more strenuous and physically demanding than others such as concreting works (e.g. slab construction).

4. Residential construction sites identified have similar characteristics based on construction methods applied and project size.

1.8 Significance of the Study

It is important for construction managers to familiarize themselves with the prevailing environmental conditions where a construction site is located. These environmental conditions affect construction workers ability to focus on their work and as well as their ability to work at optimum levels. The study investigated the levels of heat stress exposure on construction workers in warm and humid environments and measured the prevailing environmental conditions so that the levels of heat stress risk could be evaluated. The results may be used to inform the strategies adopted by policy makers such as the National Construction Authority in reducing the number of heat related incidences, and introduce safety environmental conditions measures to be undertaken by construction managers in construction sites. The study findings may also enable various construction firms in Mombasa and other warm and humid parts of Kenya to take interest on prevailing environmental conditions for the health and safety of their workers. By Construction workers working at their optimum in warm and humid conditions, Construction firms would therefore increase their out-put. Generally, the research findings of the study will contribute to the body of knowledge concerning heat stress in warm and humid environments by acting as a reference for future research work by academics who wish to undertake further research on the topic of construction heat stress at construction sites.

1.9 Scope of the Study

The study was limited to a manageable geographical, theoretical and methodological scope.

a) Geographical Scope

The study area was confined to Mombasa County. In this region there exists a variety of formal building construction sites that are easily accessible and in close geographical proximity. Mombasa being a warm and humid environment provides the best location for the study.

b) Theoretical Scope

The study limited its theoretical scope to identified sources that discussed the effect of heat stress on workers in warm and humid construction sites, thereby positioning itself within the positivist paradigm. Positivism is a scientific world view that focuses on objectivity as a truth value which is reproducible. Other researchers can conduct the same research as was done in this study and their measurements and observations will have findings and conclusions that are consistent with this study. Heat in warm and humid environments affects the construction workers in two main ways: Firstly, through working rate capacity and heat related health and safety issues: Palmer and Creagh (2013) noted that if the humidity increases then work ability decreases. Xiang et al. (2014) found that construction workers were the most likely to be affected ny climatic heat stress, closely followed in second place by agricultural workers. Chan et al. (2013) studied the design of construction workers anti-stress clothing in the hot and humid climate of Hong Kong. Findings for the research were associated with recommendations by the Hong Kong Construction Industry Council guidelines. The guidelines recommended that construction workers should continue wearing their clothing in the form of light coloured, loose fitting clothing. Furthermore fabrics worn should be thin. Vapour permeable with manageable liquid moisture and UV protective properties.

Second, Rawlinson et al. (2014) identified the six major impacts of climate heat stress, including temperature, humidity, wind velocity, radiant heat, clothing effects that mitigate heat exchange between the environment and the body, and metabolic heat generated by physical activity. Factors have been identified. Climate thermal stress elements add to psychological and physiological illnesses such as dehydration, cramps, malaise, and heat stroke.These psychological and physiological discomforts have an impact on a workers performance. Yi and Chan (2012) summarized work and recovery time for heavy workload whereby rest was distributed between 5 minutes to 15 minutes at WBGT levels of 28.5◦C to 29.7◦C . At WBGT above 31.6◦C, workers were advised to work at self-pace. These findings informed the manner in which the research methodology in this study was undertaken.

c) Methodological Scope

This study sought to assess the risk of heat stress and ensure the health and safety for construction workers during hottest months in the hot and humid environment of Mombasa, Kenya. Thus, it was an enquiry to gather facts and figures on the present work activities undertaken by construction workers in a construction site and their health and safety during the hottest months in Mombasa. Therefore, the researcher used a descriptive research design, conducted the observations and measurements through field survey; and employed a quantitative method approach for data collection using the WBGT as a research instrument and American Conference of Governmental Industrial Hygienists (ACGIH) guidelines. ISO 7243 uses WBGT in its guidelines and it is also used for monitoring and assessing hot and warm environments across the world as a simple index.

1.10 Limitations of the Study

i. Due to the nature of the study which requires a specific region, the study focused only on Mombasa County, but its findings may be generalized to other regions of Kenya where construction workers may experience similar or related environmental conditions.
ii. The study focused on construction work carried out during daytime.
iii. The study only focused on only 5 categories of construction workers namely; steel reinforcement, walling, formwork concreting and roofing.
iv. Lack of previous research studies on the topic of assessment of heat stress on construction workers in the Kenyan construction industry was a limitation and not an impediment. This required the author to refer to prior relevant research studies from other countries.
v. The study was limited to the thermal environment, the clothing worn by construction workers and the nature of the physical activities undertaken in a construction site.
vi. The study was not funded by any organization and it was the duty of the researcher to provide his own funding.

1.11 Delimitations and Exclusions of the Study

The study assessed heat stress levels on construction workers at construction sites that are warm and humid. The sites were located in all the six sub-counties of Mombasa. However, the study by self-delineation did not delve into heat stress aspects arising from the issues outlined below.

i. The health conditions, worker behavior such as taking of alcohol and variables such as, weight, height, heart rate, perspiration rate and metabolism of construction workers were not examined because the research, by self-delineation, would not be able to tackle demographic and medical backgrounds of the participants.

ii. Workers at construction sites not undertaking construction and/or inactive construction sites where construction was not being undertaken at the time of study.

iii. The following have been excluded from the study:

- Construction sites that are not in Mombasa County
- Non-formal construction sites that are not approved for construction by NCA.
- Construction work being undertaken during night-time.

1.12 Organisation of the Study

Chapter One

This chapter presents and discusses; the introduction, problem statement study objectives, hypothesis, study justification, study scope, study limitation, research methods, study assumptions, data collection methods and study organization. The study furthers provides a definition of terms as used in this study.

Chapter Two

This chapter entails the critical review of relevant literature obtained from peer reviewed journals, theses and dissertations, tertiary level textbooks, magazines, and appropriate websites.

Chapter Three

This chapter comprises of a detailed research methodology that were applied in this research study. These include; research strategies, the targeted population, sampling procedures, the techniques of data collection, analysis and interpretation techniques. Contained here is a checklist of predetermined necessary data to be obtained in the field work.

Chapter Four

The chapter provides an analysis and interpretation of data and results from the field investigations that were conducted at the construction sites. The findings and analysis are in the form of comparative tables and other presentation techniques such as plots, charts and graphs.

Chapter Five

The chapter presents the findings, and also provides recommendations and conclusions of the study on the basis of objectives the study was tackling that were outlined in Chapter One. It also proposes other areas for further research.

1.13 Definition of Key Terms used in the Study

Heat Stress

“Heat stress” is referred to as body heat received in excess that cannot be tolerated by the body without physiological impairment (Kjellstrom et al.,2016).

Heat Acclimatization

Heat adjustment or acclimatization occurs when recurrent natural or artificial heat exposures which are stressing and increases the core body and skin temperatures. These adaptations results in the reduction of physical strain which allows for improved comfort, enhanced capability for physical activity and reduces the danger of heat related health problems through exposure to heat stress (Sawka, Periand and Racinais, 2016). A person is able to work effectively with less chance of injury.

Heat Exhaustion

Heat stroke if often caused by heat exhaustion. Heat exhaustion is usually accompanied by an increased core body temperature of around 38°C to 39°C. Symptoms such as fatigue, head-ache, dizziness, fatigue, weakness, sweating profusely, feeling thirsty nausea, and a decrease in urination may be experienced (OSHA, US., 2020).

Thermal Environment

Thermal environment are the physical surroundings or and its aspects that affect a person or population and their environment in terms of exchange of heat exchange. When looking at environmental stress, thermal environments represent the primary stress potential of the physical environment (Santee, 2019).

Wet Bulb Globe Temperature (WBGT)

WBGT is a combination of a weighted average between different measures of heat. These include wet-bulb, globe and dry-bulb/air temperature which when combined reflects the effects of humidity, temperature of the environment, sun rays and wind. (Lemke & Kjellstrom, 2012). It is used in the measurement of performance of athletes, soldiers and in this case outdoor workers such as construction workers. WBGT has been commonly used widely as a method of assessing stress in hot and humid thermal environments

Work

These are physical efforts undertaken using energy from the body's metabolism. Work is therefore coordinated activities that expend energy with the intention of producing something that is worthwhile (Fryer and Payne, 1984). The SI unit of work is the joule (J)

Work-ability

This is described as the outcome of the interaction between a worker and his or her work. Work-ability may also be referred to as a balnce of a workers' resources and their demands (Ilmarinen, 2004).

Work-capacity

Work-capacity can be described as ability to execute real physical work. This ability can be assessed by looking at endurance, energy efficiency, aerobic capacity, voluntary activity and productivity (Haas & Brownie, 2001).

Metabolic Work-rate

This is heat produced by the body during work because of exerting energy (ACGIH, 2017). Metabolic work-rates is a representative of the impacts to the core body temperature from heat formed internally as physical exertion is increased. (OSHA US, 2020).

Thermal Mass

It is regarded as a material's ability to absorb and store energy. Heat energy is essential to change the temperature of high density materials like blocks, tiles and concrete resulting into high thermal mass. (Reardon, 2020).

Heat Strain

This is the total of physiological responses of an individual to heat stress. The body attempts maintain a stable temperature through increase in the heat lost to the environment. These responses are as a result of physiologically removing heat that is in excess from the body (OSHA Canada, 2020).

Globe Temperature (tg)

This is the temperature inside a spherical, black and hollow thin globe made of copper with a thermometer for measurement. The thermometer's sensor is placed at the center inside the sphere. The temperature of the globe thermometer resembles the thermal conditions felt by the human body (NIOSH, 2016). It is measured in Degrees Celsius (°C). or Degrees Fahrenheit (°F).

Heat Stroke

It is an acute medical emergency which is caused by heat exposure because of excessive rise in body temperature and failure of the mechanism that regulates temperature of the body. The central nervous system is affected causing headaches, inexplicable actions, nausea, body temperature that is excessive and a sudden loss of consciousness (NIOSH, 2016).

Relative Humidity (RH)

This is the ratio of water vapour in ambient air to the water vapour present in saturated air at the same temperature and pressure. It simply shows how much water vapour is in the air copared to how much it can hold at a particular temperature (NIOSH, 2016). Relative Humidity therefore is represented as a percentage.

Heat Exposure

This is the contact between a human and the environment whereby the air temperature, radiation, moisture in the atmosphere and air velocity/wind in collectively put a person at risk of increased body core temperature and perceived discomfort (Kuras et al., 2017).

Metabolic Rate

Metabolic rate is a rate whereby chemical energy is used by the body and converted into heat (ANSI/ASHRAE, standard 55, 2010). It is measured in Watts. The rate of metabolism is the amount of energy used over a certain period of time.

1.14 Conclusion

In this chapter, a background to heat stress on construction workers and hot and humid environments was discussed. Additionally, the problem statement which anchors the study, the hypothesis and the associated research questions and objectives were outlined. The study assumptions, significance and scope were discussed. Limitations including limitations of region of the study and delimitations were elaborated. A review of past literature on construction workers, occupational factors, heat stress levels and its measurement is presented in Chapter 2.

CHAPTER TWO

LITERATURE REVIEW

2.1 Introduction

Problems concerning heat stress are characteristically addressed by: regulations, governments guidelines, policies, participation by the public, research recommendations and the education industry (Li & Baldwin, 2018). In Kenya, the nature of the construction industry is mainly through local practices and agreements. There are no enforceable guidelines on working under heat stress levels that are acceptable by International Regulations (Li & Baldwin, 2018). This chapter reviewed literature on three general aspects namely heat stress, assessment of heat stress and heat exposure. To represent the association between physical activity, heat exposure and heat stress a conceptual framework was then developed for this study.

The chapter initially reviews heat stress and how it affects construction workers in warm and humid environments in the building and construction industry. Literature review on heat waves and heat levels in Africa is discussed. This includes looking at the consequences of the anticipated increase in heat levels over the years to come. The chapter further delves into the factors that influence heat stress and its impact to construction workers and further studies heat stress index and the procedures that are used to measure heat stress outdoors, most commonly WBGT and Humidex Index. Secondly the chapter looks at physiological response from the human body resulting from heat stress exposure, which is heat strain. Furthermore Acclimatization will be discussed**.** This includes the issue of workers adaptation to the hot and humid environments and how the Clothing affects Heat exchange. Finally we will look at how metabolic heat is estimated and its relationship with WBGT. The study also reviewed literature concerning common construction practices in slab casting in Mombasa and past studies undertaken by researchers on heat stress. This includes how heat stress affects productivity and how construction workers are prone to accidents on construction sites due to heat stress. Study gaps on Heat Stress and Heat stress Standards and Guidelines including OSHA Regulations will also be reviewed.

2.2 Heat Waves and Future Heat Levels in Africa

Africa is a vulnerable continent when it comes to climate change. Frequent heat waves could have a huge impact on mortality rates in the decades to come because of hotter, frequent and longer heat waves (Russo, et al., 2016). Studies have shown that in the recent years these frequent hot and longer heat waves have been experienced in Africa compared to the last two decades of the 20th century. It is predicted that heat waves will become a regular occurrence even in regions that are these heat waves are not common under the current climate. This change could occur as frequently as every season in any country in Africa because of the rising global mean temperatures. The two warmest years recorded globally were 2010 and 2015 where Africa was struck by intensive heat waves (Russo, et al., 2016).

Those living in warm climates will have to endure environmental conditions that are not tolerable. There is a need to therefore take action and carry out planning for adaptation in these environments with urgency. Living conditions for a large population of inhabitants may become unbearable in decades to come (University of Virginia, 2018). Asefi-Najafabady et al., (2018) used sophisticated computer modelling tools to study the climate. The tools enabled the prdiction of future state of the atmosphere, land surface and human activities to generate scenarios that will enable the understanding of potential impacts of climate change. The study found out that Kenya currently experiences between 20 to 25 days of dangerous heat per year. In the year 2090, the dangerous heat could be more than 125 days (Asefi-Najafabady et al., 2018). In every month between October 2019 to April 2020, Mombasa experienced some days of the month with maximum day temperatures of above 28°C. The month of March, 2020 was the hottest of these months. Such high temperatures coupled with high humidity can cause heat stress.

2.3 Heat Stress

Heat stress is known to occur when the human body does not have the ability to cool itself in order to maintain a normal body temperature. Moderate stress may cause discomfort which could have an effect on workability and safety but this is likely not to be detrimental to one's healthiness. The risk of a heat related illness surges when the body undergoes heat stress that is greater than the tolerance limits (OSHA Canada, 2020). Failure to replenish the body with water which is lost in warm and hot environments during activities such as construction predisposes the individual to certain heat disorders such as heat exhaustion and stroke caused by heat. Research has shown that situations of heat exhaustion are likely to happen ten more than heat stroke situations (ACGIH, 2017).

2.4 Heat Stress and its Effects on Construction workers

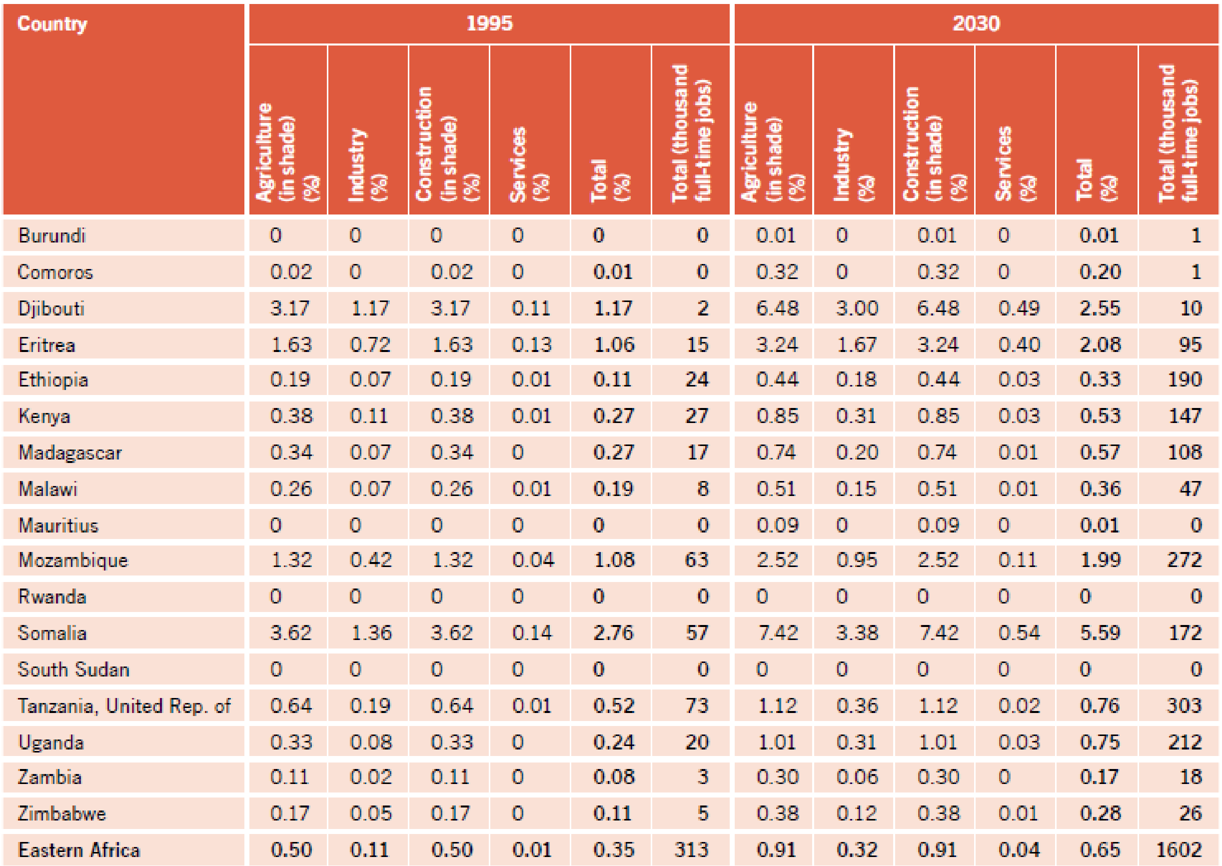
Heat stress as a measure, combines air temperature, wind speed and RH to represent the conditions in warm climates. These environmental conditions have an impact on humans and other species therefore it is more representative to use heat stress than just using temperature (University of Virginia, 2018). The strenous and physical nature of construction work that are located in environments with consistent high daily temperature shows rthat climatic heat stress is a predominant phenomenon among construction workers (Li & Baldwin, 2018).

Among those predominantly affected by heat stress are workers in the construction industry. The reason being that construction workers carrying out physical and demanding work at construction sites produce immense body heat due to the warm or hot and humid environment (Yi & Can, 2017). Construction workers are vulnerable to heat stress because majority of them participate in heavy work in the open outdoors. Construction workers in Africa and other parts of the world are frequently exposed to high temperatures which can be considered extreme. These workers sometimes have limited or no access to water or sometimes shade and yet they work for long hours at a time (Acharya et al., 2018).

Heat stress can make construction workers undergo physiological impairment and this can subsequently lead to reduction in work enthusiasm, increased accident rate and reduced productivity (Chan et al., 2012). The construction industry has a high number of work related injuries which are sometimes fatal and therefore a priority area for research and interventions. Exposure to high temperatures, solar radiation and humidity together with physically demanding works can additionally increase the physical stress during work especially in cases where there is poor air ventilation (Tiwaria & Giteb, 2006). Heat stress incidences have been alarming because many verifiable deaths have been reported in the construction industry (Chan et al., 2012).

In Hong Kong, Preventive measures have been taken towards heat stress such as work and break cycles and facilities to cool down to protect construction workers during extreme warm or hot weather. The purpose of work-break schedule is to balance the demands of productivity with safety taking into consideration the strenuous load workers go through. Properly designing work and rest schedules is an effective way of improving the comfort of the workers because it takes into consideration their health and by resting increases workers' productivity (Chan et al., 2012).

Figure 2.1: Working hours lost to heat stress, by sector and country, 1995 and projections 2030.



Country	1995						2030					
	Agriculture (in shade) (%)	Industry (%)	Construction (in shade) (%)	Services (%)	Total (%)	Total (thousand full-time jobs)	Agriculture (in shade) (%)	Industry (%)	Construction (in shade) (%)	Services (%)	Total (%)	Total (thousand full-time jobs)
Burundi	0	0	0	0	0	0	0.01	0	0.01	0	0.01	1
Comoros	0.02	0	0.02	0	0.01	0	0.32	0	0.32	0	0.20	1
Djibouti	3.17	1.17	3.17	0.11	1.17	2	6.48	3.00	6.48	0.49	2.55	10
Eritrea	1.63	0.72	1.63	0.13	1.06	15	3.24	1.67	3.24	0.40	2.08	95
Ethiopia	0.19	0.07	0.19	0.01	0.11	24	0.44	0.18	0.44	0.03	0.33	190
Kenya	0.38	0.11	0.38	0.01	0.27	27	0.85	0.31	0.85	0.03	0.53	147
Madagascar	0.34	0.07	0.34	0	0.27	17	0.74	0.20	0.74	0.01	0.57	108
Malawi	0.26	0.07	0.26	0.01	0.19	8	0.51	0.15	0.51	0.01	0.36	47
Mauritius	0	0	0	0	0	0	0.09	0	0.09	0	0.01	0
Mozambique	1.32	0.42	1.32	0.04	1.08	63	2.52	0.95	2.52	0.11	1.99	272
Rwanda	0	0	0	0	0	0	0	0	0	0	0	0
Somalia	3.62	1.36	3.62	0.14	2.76	57	7.42	3.38	7.42	0.54	5.59	172
South Sudan	0	0	0	0	0	0	0	0	0	0	0	0
Tanzania, United Rep. of	0.64	0.19	0.64	0.01	0.52	73	1.12	0.36	1.12	0.02	0.76	303
Uganda	0.33	0.08	0.33	0	0.24	20	1.01	0.31	1.01	0.03	0.75	212
Zambia	0.11	0.02	0.11	0	0.08	3	0.30	0.06	0.30	0	0.17	18
Zimbabwe	0.17	0.05	0.17	0	0.11	5	0.38	0.12	0.38	0.01	0.28	26
Eastern Africa	0.50	0.11	0.50	0.01	0.35	313	0.91	0.32	0.91	0.04	0.65	1602

Source: ILO (2019)

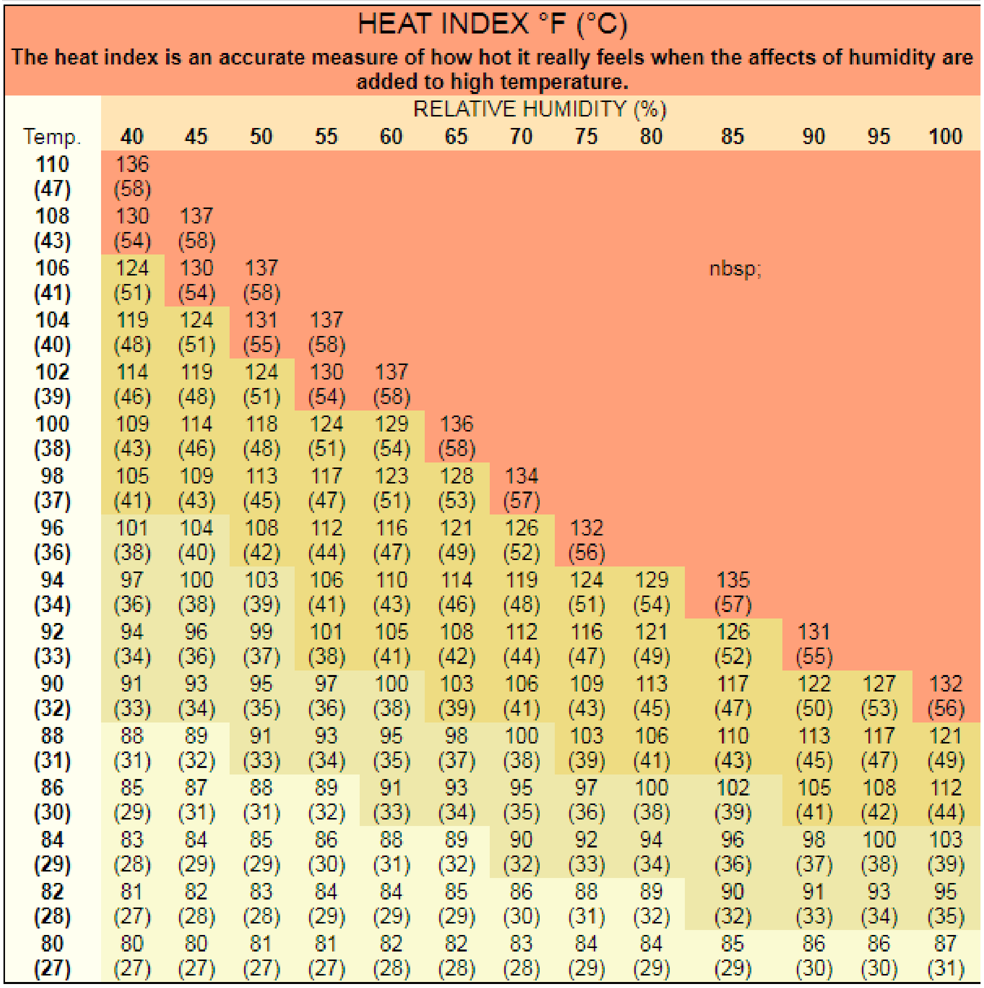
Dutta et al. , (2015) discovered that construction laborers at construction sites are fully cognizant of the challenges of thermal stress. These workers knew how precautions could help overcome heat stress, but they lacked the means to protect themselves. Climatic heat stress was regularly higher than recommended by international standards. Figure 2.1 above shows the percentage of time lost due to heat stress. It also shows the impact on health and productivity of each sector of the economy as a whole. It also shows the equivalent loss in terms of fulltime labour for the economy as a whole. Construction and Agriculture is assumed to be carried out under shade. Heat stress Index for work carried out in the afternoon sun adds about 2 to 3°C to the inshade WBGT. The data in fig. 2.1 are based on historic observations and on estimates using Representative Concetration Pathway 2.6 (RCP2.6) climate change pathway that predicts a lobal average temperature rise of 1.5°C by the end of the current century (International Labour Organisation, 2019). RCP2.6 is a greenhouse gas enrichment route adopted by the Intergovernmental Panel on Climate Change (IPCC). As East Africa is Africa's most densely populated subregion, rising and rising climate temperatures increase productivity declines. According to Figure 2.1, Kenya's loss in 2030 is projected to be 0.53%, which is equivalent to about 147,000 jobs. Tanzania peaked with a projected loss of 0.76 percent, equivalent to 303,000 unemployment by 2030. Agricultural and construction workers are expected to be hit hardest, but urban informal workers can collectively be hit hard by rising temperatures (International Labor Organization, 2019).

2.5 Heat Stress Index

Heat stress Index is the amount of perspiration or evaporation which essential to the maximum capacity of an individual’s perspiration. According to USA Dept of Commerce (2020), heat Index is defined as the measure of hotness one feels when relative humidity is included in the air temperature. There should be an application of safety regulations in construction projects in hot weather environments. Most regulations regard the effect of combining relative humidity and ambient temperature as the Heat stress Index (Shehata & El-Gohary, 2012). Heat stress index are regarded as majorly for indoor use with the WBGT for both indoor and outdoor measurements.

Fig. 2.2 shows the Heat Index chart which displays air temperature and Relative Humidity along axes. The background of the chart is covered in different colours from yellow to red. ‘Yellow’ means that one has to be careful in the conditions they are in and red means ‘Danger’.

Figure 2.2: Heat Index Chart



HEAT INDEX °F (°C)

The heat index is an accurate measure of how hot it really feels when the affects of humidity are added to high temperature.

	RELATIVE HUMIDITY (%)												
Temp.	**40**	**45**	**50**	**55**	**60**	**65**	**70**	**75**	**80**	**85**	**90**	**95**	**100**
110 (47)	136 (58)												
108 (43)	130 (54)	137 (58)											
106 (41)	124 (51)	130 (54)	137 (58)							nbsp;			
104 (40)	119 (48)	124 (51)	131 (55)	137 (58)									
102 (39)	114 (46)	119 (48)	124 (51)	130 (54)	137 (58)								
100 (38)	109 (43)	114 (46)	118 (48)	124 (51)	129 (54)	136 (58)							
98 (37)	105 (41)	109 (43)	113 (45)	117 (47)	123 (51)	128 (53)	134 (57)						
96 (36)	101 (38)	104 (40)	108 (42)	112 (44)	116 (47)	121 (49)	126 (52)	132 (56)					
94 (34)	97 (36)	100 (38)	103 (39)	106 (41)	110 (43)	114 (46)	119 (48)	124 (51)	129 (54)	135 (57)			
92 (33)	94 (34)	96 (36)	99 (37)	101 (38)	105 (41)	108 (42)	112 (44)	116 (47)	121 (49)	126 (52)	131 (55)		
90 (32)	91 (33)	93 (34)	95 (35)	97 (36)	100 (38)	103 (39)	106 (41)	109 (43)	113 (45)	117 (47)	122 (50)	127 (53)	132 (56)
88 (31)	88 (31)	89 (32)	91 (33)	93 (34)	95 (35)	98 (37)	100 (38)	103 (39)	106 (41)	110 (43)	113 (45)	117 (47)	121 (49)
86 (30)	85 (29)	87 (31)	88 (31)	89 (32)	91 (33)	93 (34)	95 (35)	97 (36)	100 (38)	102 (39)	105 (41)	108 (42)	112 (44)
84 (29)	83 (28)	84 (29)	85 (29)	86 (30)	88 (31)	89 (32)	90 (32)	92 (33)	94 (34)	96 (36)	98 (37)	100 (38)	103 (39)
82 (28)	81 (27)	82 (28)	83 (28)	84 (29)	84 (29)	85 (29)	86 (30)	88 (31)	89 (32)	90 (32)	91 (33)	93 (34)	95 (35)
80 (27)	80 (27)	80 (27)	81 (27)	81 (27)	82 (28)	82 (28)	83 (28)	84 (29)	84 (29)	85 (29)	86 (30)	86 (30)	87 (31)

Source: US Dept of Commerce, National Oceanic and Atmospheric Administration, (2020)

2.6 Measuring Thermal Stress

Thermal stress is viewed as a thermal load that a person is exposed to due to metabolic heat, wearing clothes, and contributions from environmental influences, and increases heat storage in the body. The heat stress experienced by workers causes a reaction called heat stress. This physiologically increases the body's heat loss and maintains normal body temperature. The body is not always chilled, and the temperature may remain at high levels, which can lead to heat injuries and death. The body's metabolic heat is generated in proportion to the intensity of physical work and contributes to heat stress. The thermal environment and construction clothing worn and the type of work clothes also contribute to heat exchange between the body, skin and air (NIOSH, 2016).

2.7 Environmental Factors That Affect Heat Stress and their Assessment

According to Li & Baldwin (2018), Rowlinson, et al. (2014) identified 6 main parameters that affect climatic heat stress. These are as follows:

- Temperature of the air
- Relative Humidity
- Radiant heat
- Wind speed
- Metabolic heat generated by physical activity
- The action of clothing involved in heat exchange between the body and the environment

The parameters mentioned above make a contribution to physiological and psychological discomforts such as heat exhaustion, dehydration, heat stroke and cramps that are likely to have a negative reaction towards the performance of duties of a worker. Thermal stress is usually assessed by measuring environmental parameters and further assessing their effects on the human body through related indices such as the WBGT and Humidex index. To tackle this one can also measure the heat load which is the amount of heat experienced by the worker (NIOSH, 2016).

2.7.1 Air Temperature and its Measurement

Dry Bulb Temperature

In retrospect, thermometers have used mercury and alcohol. Mercury glass thermometers are ideal for high temperature conditions, but alcohol glass thermometers are more suitable in cold environments. This is because the freezing point of mercury is 40 ° C and the freezing point of alcohol is 114 ° C. (NIOSH, 2016).

Precautions to be considered when using a thermometer:

- The element that senses should be in contact or as close as possible to the area of interest.
- The thermometer should be given sufficient time to stabilize while the temperature is being taken.
- measured temperature has to be within range of the thermometer
- The sensing element should be shielded from area under radiant conditions.

Natural Wet Bulb Temperature (tnwb)

Natural Wet Bulb Temperature is the lowest temperature that can be cooled by the evaporation of water and is measured by a thermometer whose sensor is wrapped in a wet core. This is usually measured using a psychrometer. The psychrometer measures both the dry-bulb and wet-bulb temperatures of a clean, moist cotton core (NIOSH, 2016). At 100% relative humidity, the wet-bulb temperature is equivalent to the air / dry-bulb temperature, but at lower humidity levels, the wet-bulb temperature is lower than the dry-bulb temperature due to evaporative cooling.

2.7.2 Relative Humidity and its Measurement

Humidity can be described as the amount of water vapor in a particular space. Humidity is measured as relative humidity. This is the percentage of moisture in the air that can be retained when saturated at a particular temperature. Humidity is a significant parameter because it is a temperature-dependent equation of the actual water vapor pressure. Water vapor pressure is the most important environment variable that affects the heat exchange between the body and the environment through the evaporation process. Sweat and subsequent evaporation lead to cooling of the human body. Higher water vapor pressure leads to lower heat of vaporization loss. The tool used to measure humidity is known as a hygrometer or psychrometer (NIOSH, 2016).

2.7.3 Measuring Radiant Heat

Radiant heat is heat transmitted through electromagnetic waves. The most commonly used device for measuring heat radiation is globe thermometer that is painted black. Black globe thermometers are preferably used to measure thermal stresses on humans due to solar and infrared radiation.This is because a globe thermometer picks up the radiation from surfaces surrounding a particular point. Radiation has an influence on the human body and readings from the black globe thermometer are considered to resemble thermal conditions felt by the human body.

Black Globe Thermometer

The thermometer consists of a 15 cm or 6 inch hollow copper ball called a globe and is painted in matt black to absorb infrared heat. In addition, a mercury thermometer sensor is inserted in the center of the globe to record the readings. The National Institute for Occupational Safety and Health (NIOSH) recommends the Black Globe Thermometer, known as the Vernon Globe Thermometer, to measure radiant heat in the workplace.

Black globe thermometers use radiation and convection to exchange heat with the environment. The temperature of the black bulb thermometer become stable when the heat exchanged by radiation equals the heat exchanged by convection. The globe size is involved in stabilization time and conversion of globe temperature to Mean radiant temperature (Kuehn 1973; (NIOSH, 2016). The 6-inch Vernon thermometer is considered the industry standard as ISO 7243 2008. However, other newer and smaller handheld WBGT units are available. The principle is the same whether using a Vernonn Globe thermometer or a handheld WBGT unit (Parsons 2003; McArdle et al., 2010b). (NIOSH, 2016). There is no significant difference between the two measurements, as the measurements are relatively good with a slight difference when using a Vernon Grove thermometer or a handheld WBGT device.

Mean Radiant Temperature

Mean radiant temperature (MRT) is an average measurement of the surface surrounding a particular point. Radiant temperature (tg) is used to calculate the Mean radiant temperature. The

MRT of the standard 150 millimeter / 6 inch black globe sphere can be determined using the following formula:

MRT: tg +(1.8Va $^{0.5}$) (tg-ta)

where,

MRT : Mean radiant temperature (° C)

tg : Black globe temperature (° C)

ta : Temperature (° C)

Va : Airspeed (ms^{-}1)

Source: NIOSH (2016)

Other devices used to measure radiation include:

Radiometer: A radiometer is a device that measures infrared radiation. An example includes the infrared thermometer that uses the recorded radiant energy to show the surface temperature of the source. This is done by measuring the radiation from an object that emits heat (NIOSH, 2016).

Pyroheliometers

Solar radiation can be classified as direct radiation, reflected radiation, or diffuse radiation. Therefore, the total solar heat load is the sum of pyroheliometers, reflected solar radiation, and diffuse solar radiation.This is then checked against clothing put on and the body position relative to solar radiation (NIOSH, 2016).

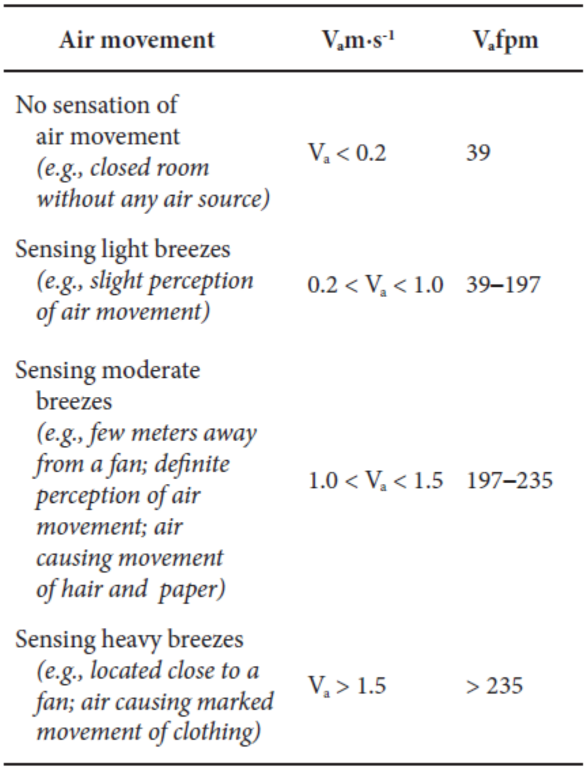
2.7.4 Air Velocity and its Measurement

Wind cools the body through evaporation and convection and is therefore this is vital for heat exchange between the human body and the environment. An anemometer measures wind velocity. There are two main types of anemometers, these are

- thermo-anemometers
- wind vane anemometers

According to NIOSH (2016), Ramsey & Beshir (2003) noted that when there isn't the availability of an anemometer for precise airspeed, the airspeed can be estimated as shown in fig. 2.3.

Figure 2.3: Air Velocity Estimates



Air movement	$V_a m\cdot s^{-1}$	$V_a$fpm
No sensation of air movement *(e.g., closed room without any air source)*	$V_a < 0.2$	39
Sensing light breezes *(e.g., slight perception of air movement)*	$0.2 < V_a < 1.0$	39–197
Sensing moderate breezes *(e.g., few meters away from a fan; definite perception of air movement; air causing movement of hair and paper)*	$1.0 < V_a < 1.5$	197–235
Sensing heavy breezes *(e.g., located close to a fan; air causing marked movement of clothing)*	$V_a > 1.5$	> 235

Source: Ramsey & Beshir (2003); NIOSH (2016)

2.8 Assessment of Environmental Variables using WBGT

WBGT is used to record occupational environments by the usage of air temperature, humidity, radiant load and wind. WBGT additionally serves as a the metric for thermal stress standard recommended by the International Organisation for Standardisation ISO 7243 that's used for determining ergonomic impacts of thermal environments. Even though WBGT has its limitations when it comes to measuring metabolic rates and wind speed effects, it is still an important measure of the effects of heat (Acharya et al., 2018).

To determine heat hazards in indoor and outdoor workplaces, environmental factors are measured. After the WBGT is calculated, the adjustment in clothing is factored in and workload converted into metabolic rate. ACGIH Threshold Limit Values (TLV) and Action Limit table is used to find out about the risk of exposure to heat stress. Action Limit (AL) is used for determining risk of un-acclimatized workers while TLV for workers who are acclimatized (NIOSH, 2016).

WBGT can be used to measure both indoor and outdoor environments as follows:

1. Measuring WBGT for outdoor environments with direct exposure to the sun:

   WBGT = (0.7 x Tnwb) + (0.2 x Tg) + (0.1 x Tdb)

2. Measuring WBGT for indoors or outdoors without direct exposure to the sun:

   WBGT = (0.7 X Tnwb) + (0.3 x Tg)

Where:

WBGT : Wet Bulb Globe Temperature

Tnwb : Natural Wet-Bulb Temperature

Tg : Globe temperature

Tdb : Dry-Bulb air Temperature

Source: NIOSH (2016)

In the calculation of WBGT, three inputs are required. These include the natural wet-bulb temperature (Tnwb), Globe Thermometer (Tg) and the dry bulb temperature (Tdb). Natural wet-bulb temperature reflects humidity and is provided by a thermometer with a damp wick. natural wet-bulb temperature is heavily weighted in the equation. The Globe Thermometer (Tg) measures the temperature inside a black painted 15 centimeter hollow copper sphere and the Dry bulb mearsures air temperature with a thermometer exposed to air.

2.9 Prediction of Heat Stress using Meteorological Factors from the National Weather Service

Kenya Meteorological Department provides daily weather forecasts that can be used by construction managers to combat heat stress. These forecasts can be useful in supplementing environmental factors measured at the construction site. These set of facts which includes air temperature, wind, Relative Humidity, dew factor and visibility may be used to approximate the evaluation of a Construction site thermal loading for jobs carried outdoors which includes slab casting and reinforcement bar creation. The actual and projected records may be useful in predicting local WBGT (NIOSH, 2016). Meteorological records may be of significance when predicting thermal stress for a day or days. The issue is that WBGT is primarily based totally on climatic measurements with specially designed sensors and its relation to the primary climate data is complicated (Gaspar & Quintela, 2009). Several research have evolved formulation for prediction of WBGT from meteorological records however they are considered complex due to their generality of the bigger geographical region as opposed to nearby locations in which humans are exposed. Measuring WBGT on site, or the usage of archival WBGT records are the most accurate and encouraged strategies to make work-rest decisions or to evaluate the danger after a thermally associated incident.

2.10 Heat Strain

Thermal Strain is the physiological impact as a consequence of thermal stress. These responses are as a result of physiologically removing heat that is in excess from the body (OSHA Canada, 2020). Under similar thermal stress situations, the risk and severity of thermal strain usually varies among individuals.

Normal physiological reactions of a body towards thermal stress provide a chance to observe thermal strain and this information can be used to give facts on the levels of thermal strain midst workers (ACGIH, 2017). The body naturally keeps core body temperature from rising to levels that are unhealthy through sweating and increase in heartrate. Individuals can experience heat-related illnesses and even death, unless the body prevents the core body temperature from rising to unhealthy levels. According to NIOSH (2016), when core body temperature rises to dangerous levels, it can cause the following illnesses:

- Heat Cramps
- Heat Stroke
- Heat Exhaustion
- Heat Syncope
- Heat Rash
- Rhabdomyolysis

2.11 Acclimatization

Adaptation is a step-by-step physiological adjustment to a particular environment, improving a person's ability to withstand thermal stress. To withstand thermal stress, adaptation involves physical activity under thermal stress conditions similar to those expected for work. (OSHA Canada, 2020).

Construction workers readily show some signs of discomfort and distress such as the rise in body temperature, increased heart rate, headaches and sometimes nausea when exposed to hot and humid work environments. Employers should implement a structured program to assist construction workers to adapt to the heat environment in their work places especially outdoors. This will reduce the impact of heat stress. An acclimatization program that can be considered efficient for a non-acclimatized workers increases every day over a period of 7 to 14 days while the construction worker conducts the daily work routine. Acclimatized workers not exposed to heat stress for duration of one week or more sometimes require about 2 to 3 days to re-acclimatize.

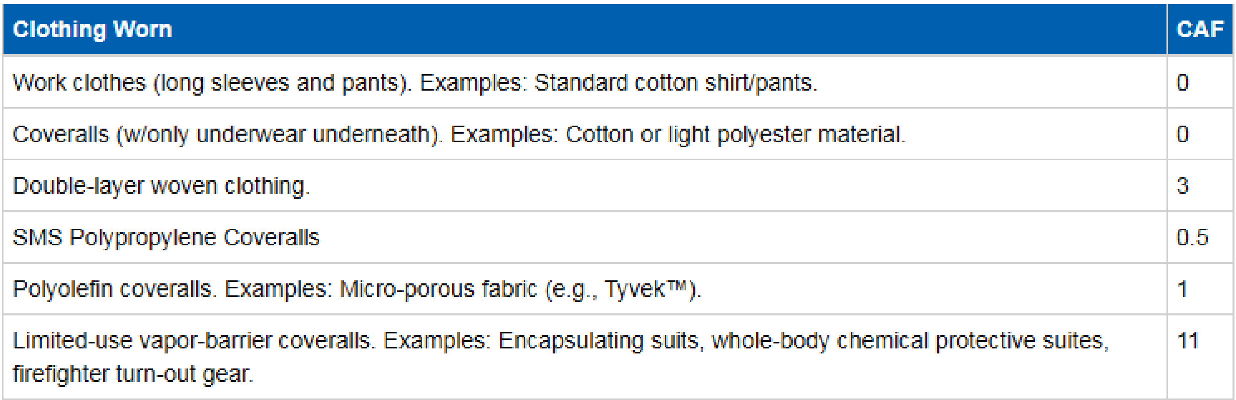
The minimum time of exposure in order to achieve acclimatization in the heat is 2 hours each day. This can be broken down into two exposures of 1 hour (Sawka, 2015). When acclimatization occurs the production of sweat increases and sweating occurs at a lower body temperature (Sawka, 2015). Plans should be set out for acclimatization at construction sites where construction workers are likely to be exposed to an environment of heat.

2.12 Effects of Clothing on Heat Exchange

Clothing is a barricade between the environment and skin. It has the ability to protect us from heat, humidity, cold and even wear. Distinctive attire is designed to better protect the body from physical injuries, biological agents, and dangerous chemicals. Clothing definitely affects the rate of heat exchange between the skin and the air. To calculate the heat exchange, it is necessary to apply a correction factor to reflect the characteristics, type and amount of clothing worn by the person. (NIOSH, 2016). Even without clothing, a thin layer of static air, the so-called boundary layer, remains next to the skin.The external film of still air acts as an insulation layer against the exchange of heat between the environment and the skin. In instances where clothing worn encapsulates vapour and air, WBGT will not be the right heat environmental heat measure. In such cases, a regulated dry-bulb temperature should be measured and used in place of the WBGT. Physiological observation is required if the dry-bulb temperature exceeds 20 ° C (NIOSH, 2016). The method of measuring core body temperature and pulse rate is determined by reasonable advance planning and general circumstances. The surveillance system must be worn before wearing the PPE.

Studies of garment materials have shown that the thicker the garment material, the better the insulation. Differences in fibers or the weave on the fabric weave have insignificant effects on insulation (NIOSH, 2016). Rameezdeen & Elmualim (2017) noted that construction workers helmet temperatures was as high as 57°C while the environmental temperature was at 33°C , workers were tempted to take away PPE leaving them prone to accidents. Unfortunately, the need to wear permeable clothing suggests that construction workers need to be protected from serious environmental hazards that can hurt or kill them. PPE needs to be protected from this danger, but because it is a heat hazard in itself, it is necessary to investigate and protect against the heat stress caused by PPE being impermeable garments. (NIOSH, 2016).

Figure 2.4: Clothing Adjustment



Clothing Worn	CAF
Work clothes (long sleeves and pants). Examples: Standard cotton shirt/pants.	0
Coveralls (w/only underwear underneath). Examples: Cotton or light polyester material.	0
Double-layer woven clothing.	3
SMS Polypropylene Coveralls	0.5
Polyolefin coveralls. Examples: Micro-porous fabric (e.g., Tyvek™).	1
Limited-use vapor-barrier coveralls. Examples: Encapsulating suits, whole-body chemical protective suites, firefighter turn-out gear.	11

Source: OSHA, US (2020)

Ramsey (1978) who discussed guidelines for heat stress exposure was the first researcher to propose Clothing Adjustment factors (CAF) and further studies were carried out by Bernard E. Thomas (1999) under Thermal stress and protective clothing: a new approach from the United States. CAF is currently being adopted by ACGIH (Figure 2.4) as an empirical measure of garment in a WBGT-based thermal stress assessment. The CAF in Figure 2.4 shows the adjustment factor in ° C. The procedure is to identify the ACGIHCAF based on the garment worn by the worker from Table 2. Add the CAF to the WBGT to determine a valid WBGT ($\mathrm{WBGT}_{\mathrm{eff}}$).

2.13 Metabolic Work Rates

ACGIH's metabolic work rate represents the effect of internal heat on core body temperature due to increased physical activity. The work category is selected based on the workload, using the example as a guide in Figure 2.5. If various work activities are planned for the day using the activity with the highest workload, the estimated metabolic rate (MRest) will determine the possibility of exposure by exceeding the uncontrolled TLV or AL of the worker. With the lowest expected workload, you can see if other controls are needed to reduce the exposure of the work activity. If it exceeds, one may plan for construction work at another different time.

Multiply the metabolic rate from Figure 2.5 by the ratio of the workers body weight to 70kg (154 Lbs) to determine the $MR_{est.}$

$$\text{MRest} = \frac{\text{Work expectations (Watts- from Figure 2.5) x Worker body weight}}{\text{70kg or 154 Lbs}}$$

where:

MR_{est} : Estimated Metabolic rate

Work expectations (Watts from Figure 2.5) : Light(180W), Moderate(300), Heavy(415) and Very Heavy(520)

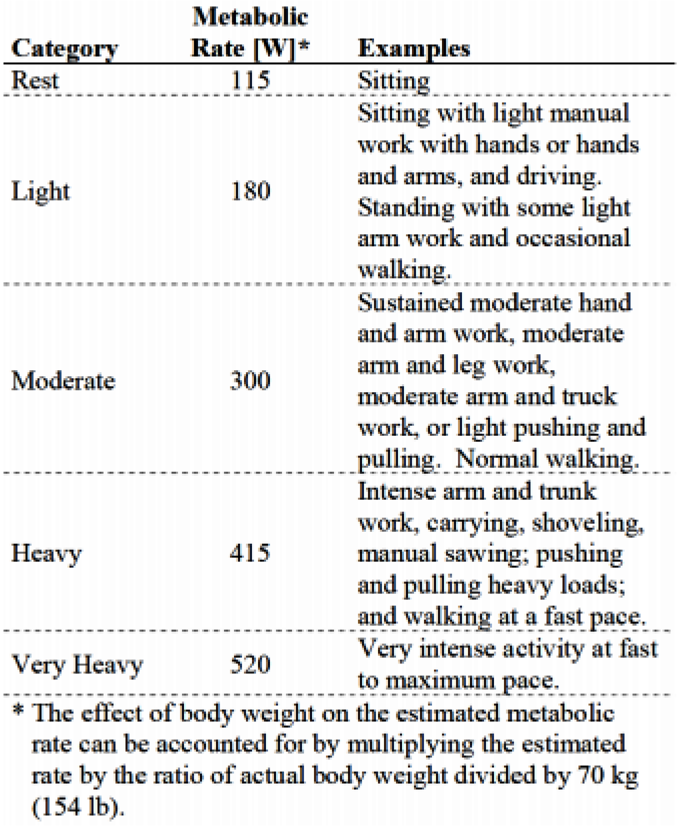
Worker Body Weight : as measured in kg

Source: Author as adapted from OSHA, US (2020)

Workload can be converted into metabolic rate using the TLV’s in ACGIH 2017 TLVs and BEIs" Table 3as shown in Figure 2.5. This is because as workload increases because of work demands and physical exertion, metabolic rate increases.

A metabolic rate increases when work demands increase. The ACGIH metabolic rate table as shown in figure 2.5 shows estimates of the metabolic rates in Watts based on the category of work demand. Construction workers who work at a moderate level represent sustained moderate hand and arm work, moderate arm and torso work, moderate arm and foot work, or light pulls and pushes. This would mean that the worker is working at an estimated metabolic rate of around 300W. The more a worker weighs the more metabolic rate. This means that the construction workers weight would give their individual metabolic rate. Working patterns and requirements must be considered when determining exposure levels to heat stress (ACGIH, 2017). If there is sufficient information about the effects of worn clothing on heat stress, the first level of detailed analysis is a task analysis that includes a Time-Weighted Average (TWA) of valid WBGT ($WBGT_{eff}$), which is the WBGT of the environment. In addition, the Clothing Adjustment Factor (CAF), and metabolic rate as estimated in Figure 2.5.

Figure 2.5: Metabolic Rate Categories and the Representative Metabolic Rate with Example Activites.



Category	Metabolic Rate [W]*	Examples
Rest	115	Sitting
Light	180	Sitting with light manual work with hands or hands and arms, and driving. Standing with some light arm work and occasional walking.
Moderate	300	Sustained moderate hand and arm work, moderate arm and leg work, moderate arm and truck work, or light pushing and pulling. Normal walking.
Heavy	415	Intense arm and trunk work, carrying, shoveling, manual sawing; pushing and pulling heavy loads; and walking at a fast pace.
Very Heavy	520	Very intense activity at fast to maximum pace.

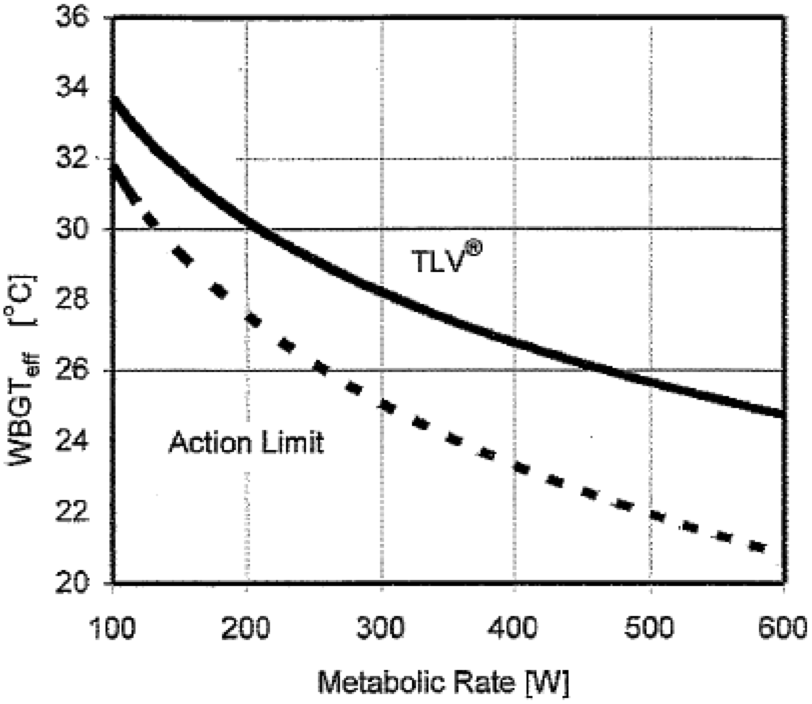
* The effect of body weight on the estimated metabolic rate can be accounted for by multiplying the estimated rate by the ratio of actual body weight divided by 70 kg (154 lb).

Source: (ACGIH, 2017)

2.14 Threshold Limit Values (TLV's) and Action Limits (AL)

The threshold (TLV) is the temperature at which the adapted worker is at risk of heat, and the action limit (AL) is the temperature at which the non-adapted worker is at risk of heat. Once these limits are reached due to either environmental factors or workload, management is needed to prevent thermal stress-related illnesses. Controls include work / break schedules, shade, and hydration (OSHA US, 2020).

Figure 2.6: ACGIH TLV & Action Limit



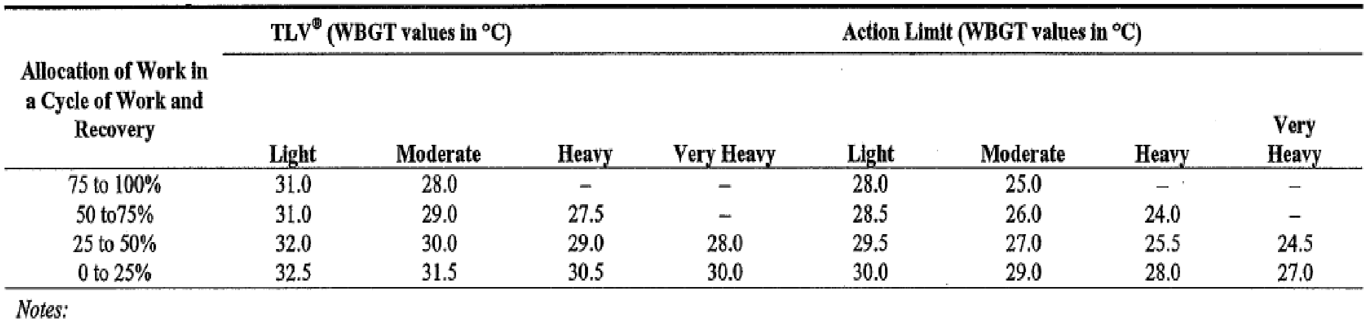
Source: ACGIH, 2017)

Figure 2.6 indicates the ACGIH TLV (continuous line) and Action Limit (dotted line) for warmth stress. $WBGT_{eff}$ is the measured WBGT plus the Clothing-Adjustment Factor (CAF). The TLV or Al is decided through the use of Figure 2.6 above. The TLV is where the $WBGT_{eff}$ and the metabolic rate interconnect with the strong line and AL is in which they interconnect with the dotted line. If there are conditions above TLV related to heat disorders such as fatigue, nausea, dizziness or light headedness then regimens such as work-rest cycles or stopping work and providing shade should be immediately applied.

2.14.1 Screening Criteria for ACGIH Threshold Limit Value (TLV) and Action Limit (AL) for Heat Stress Exposure

TLV's ACGIH screening criteria and heat stress action limits are the first screening tools to assess the presence of heat stress situations. These tables are more conservative than TLVs and ALs and are not intended to specify working hours and breaks. (OSHA US, 2020).

Figure 2.7: Screening Criteria for Heat Stress using TLV and AL



Allocation of Work in a Cycle of Work and Recovery	TLV® (WBGT values in °C)				Action Limit (WBGT values in °C)			
	Light	Moderate	Heavy	Very Heavy	Light	Moderate	Heavy	Very Heavy
75 to 100%	31.0	28.0	–	–	28.0	25.0	–	–
50 to75%	31.0	29.0	27.5	–	28.5	26.0	24.0	–
25 to 50%	32.0	30.0	29.0	28.0	29.5	27.0	25.5	24.5
0 to 25%	32.5	31.5	30.5	30.0	30.0	29.0	28.0	27.0

Notes:

Source: ACGIH (2017)

Figure 2.7 above does not show a reference value for continuous heavy or very heavy work and 25% rest due to the dangerous physical stress associated with these workloads. In these cases, detailed occupational hazard analysis and physiological monitoring should be used instead of screening criteria (OSHA US, 2020). The reference values in Figure 2.7 above have been reduced to ensure that the core temperature of most workers does not exceed 38 ° C. Another reason is that heavy and very heavy work leads to the physiological stress of unfit workers. Therefore, no reference value is given to this category.

2.15 Assessment of Heat Stress Using the Humidex Index

The Humidex Index is an index used to measure how hot or warm we feel. This is a factor intended to express how the general public perceives the combined effect of warm temperature and relative humidity. It provides numbers that explain how hot people are as shoen in Table 2.1. (CCOHS, 2020)

Table 2.1: Humidex Range and Degree of Comfort

Humidex Range	Degree of Comfort
20-29	Comfortable
30-39	Some discomfort
40-45	Great Discomfort – Avoid exertion
Above 45	Dangerous Heat stroke possible

Source: Canadian Centre for Occupation Health & Safety, 2020

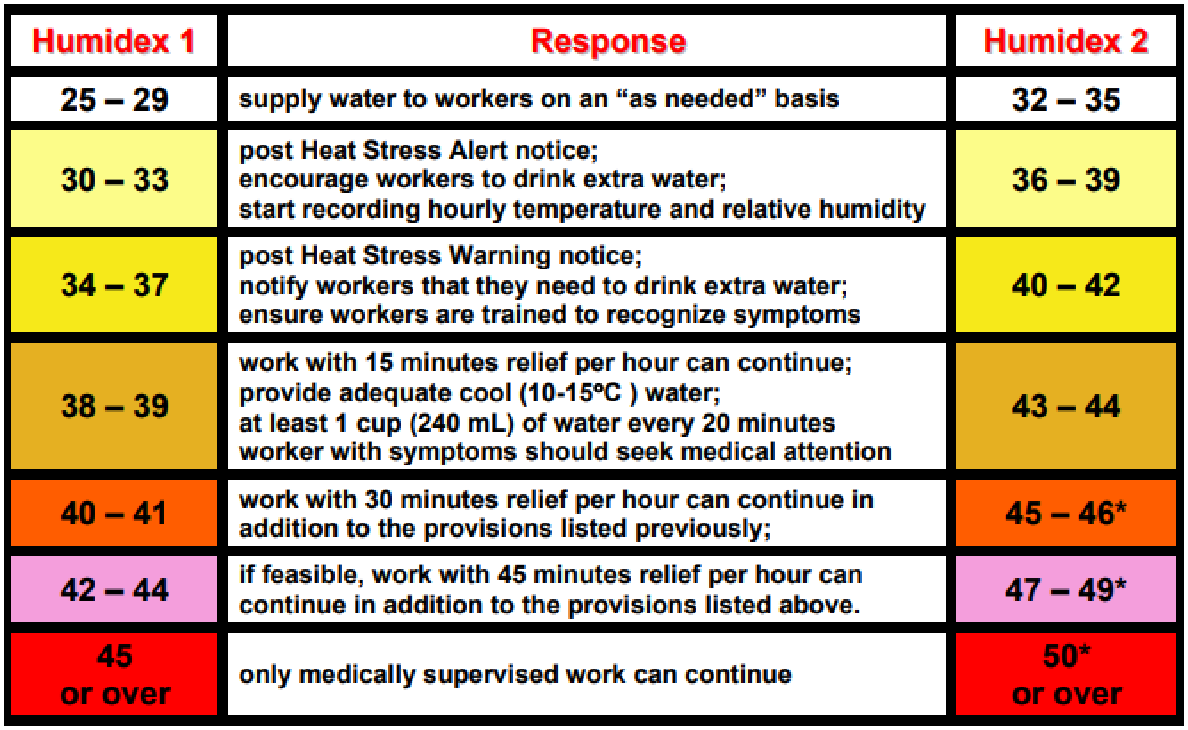
The body constantly strives to maintain a constant internal temperature of 37 ° C. In hot weather, the body sweats and evaporates to cool the body. As the humidity and moisture content of the air increases, sweat does not evaporate much. When the moisture content in the air reaches about 90%, the evaporation of sweat stops completely. This can lead to elevated body temperature in such situations and cause heat-related illnesses. In certain working environments, the area of the humidex and the level of discomfort serve as an indicator of the level of discomfort resulting from occupational heat exposure, as shown in Table 2.1 above. If you know the temperature and relative humidity, you can decide on a Humidex rating. For example, if the temperature and relative humidity are 30 ° C, and 70%, respectively, you can determine the HumidexIndex41. If the Humidex Index is 41, it is considered "great discomfort" and exertion should be avoided (CCOHS, 2020).

The Occupational Health Clinics of Ontario Workers Inc. (OHCOW) create a Humidex Index Response Plan based on the Humidex Index (Figure 2.8), convert WBGT-TLVs to Humidex values, and make recommendations for each Humidex range. Did. This plan was created as an easy-to-use workplace tool compared to the WBGT, which most people find expensive and complex. Technically, there is no direct comparison of WBGT and Humidex exponential scores. The Humidex Response Plan provides additional guidelines for using information that is readily available to most employers.

2.15.1 Humidex Based Heat Response Plan

The Humidex based index is a simplified method for protecting workers from heat stress, centered on the 2009 ACGIH Heat Stress TLV (threshold limit), which uses WBGT to estimate heat stress. These WBGTs were interpreted by Humidex. Figure 2.8 shows the recommended actions based on the ACGIHHumidexIndex and TLV values. ACGIH sets action limits (AL) and TLVs so that the worker's core body temperature does not exceed 38. Below the action limit (Humidex 1 for jobs consisting of moderate physical activity), most workers do not experience heat stress. Most healthy, hydrated, and acclimatized workers are not taking medications and can withstand the heat stress up to the listed TLVs. Thermal stress control is required between Humidex1 and Humidex2, and work-specific control is required above Humidex2.

Figure 2.8: Recommended Actions Based on the Humidex Reading



Humidex 1	Response	Humidex 2
25 – 29	supply water to workers on an “as needed” basis	32 – 35
30 – 33	post Heat Stress Alert notice; encourage workers to drink extra water; start recording hourly temperature and relative humidity	36 – 39
34 – 37	post Heat Stress Warning notice; notify workers that they need to drink extra water; ensure workers are trained to recognize symptoms	40 – 42
38 – 39	work with 15 minutes relief per hour can continue; provide adequate cool (10-15°C) water; at least 1 cup (240 mL) of water every 20 minutes worker with symptoms should seek medical attention	43 – 44
40 – 41	work with 30 minutes relief per hour can continue in addition to the provisions listed previously;	45 – 46*
42 – 44	if feasible, work with 45 minutes relief per hour can continue in addition to the provisions listed above.	47 – 49*
45 or over	only medically supervised work can continue	50* or over

Source: Occupational Health and Safety Council of Ontario (OHSCO), 2009

Humidex response plan involves: training of workers on heat stress, adjusting for clothing, selecting the measurement location and measuring workplace Humidex.

2.16 Past Studies on Heat Stress and the Study Gaps

2.16.1 Heat Stress and Work-Rest Routines

Zhao et al. (2009) studied heat tolerance in hot and humid environments and were able to establish a heat tolerance time model that determines safe work-time in warm and humid environments. The study used a chamber which was able to simulate hot and humid environments rather than a ‘natural’ setting which the researcher in this study has opted for. The study was used to determine the loss of performance due to heat stress for 204 healthy individuals aged between 19-26 years. The air temperatures were maintained at between 30°C to 40°C and RH of 40% to 90% (Zhao et al., 2009).

Chan et al. (2012) studied the maximum duration or heat tolerance time that reinforcement bar construction workers could work continuously without severely affecting their health. They determined that workers should be naturally allowed to rest in instances when such a threshold has been reached or even better before it has been reached. A WBGT index was used to develop a heat stress model. 281 sets of meteorological and physiological data were gathered from four separate sites. Physiological and environmental parameters were measured. The findings showed that appropriate work-rest pattern can be implemented to safeguard construction workers in warm and humid environments.

Chan & Yi, (2012) researched on the optimization of work and rest schedules for reinforcement bar construction workers in warm and humid environments. They were able to come up with work rest schedules. They implored the use of the Monte-Carlo technique to simulate uncertainties and variations in physiological and meteorological parameters. Instead of working to exhaustion and then resting, they came up with an optimum work rest schedule to boost productivity for construction workers.

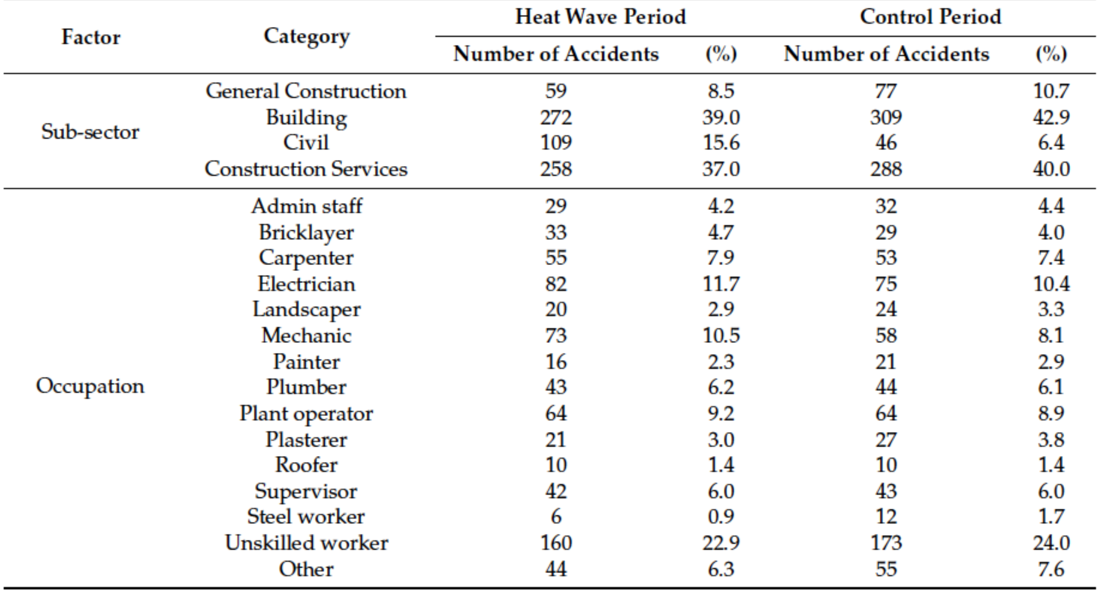
2.16.2 Heat Stress and Productivity

Hancher & Abdi-Elkhalek (1998) used the WBGT to evaluate the combined effect of hot weather on the sensory and physiological response of the human body. They found out that hot weather has an effect on labour productivity and costs. Mohamed & Srinavin (2002) studied thermal environment effects on construction workers' productivity. They found out that workers' productivity decreases when they are allowed to work away from their optimum range. According to Zhao et al. (2009), the regression models failed to accurately demonstrate productivity performance in thermal environments with the consideration of the limits of tolerance of the human body.

2.16.3 Accidents and Fatalities on Construction Sites Caused by Heat Stress

Zhao et al. (2009) indicated that there was a probability of heat stress inducing accidents during construction work leading to a fall in productivity. Rameezdeen & Elmualim (2017) researched on how heat waves impact the occurrence and severity of construction accidents. The research revealed that a workers characteristic, work environment and type of work among governed the severity of the accidents. The study noticed that there was precaution by contractors during the heat waves therefore less claims were made for accidents as compared to a control period. Construction workers habitually adjusted their pace of work so as to reduce heat strain Self-regulation is considered an effective mode of combating heat stress although the consequences noted included productivity loss.

Figure 2.9: Number of accidents caused by heat stress in Australia



Factor	Category	Heat Wave Period		Control Period	
		Number of Accidents	(%)	Number of Accidents	(%)
Sub-sector	General Construction	59	8.5	77	10.7
	Building	272	39.0	309	42.9
	Civil	109	15.6	46	6.4
	Construction Services	258	37.0	288	40.0
Occupation	Admin staff	29	4.2	32	4.4
	Bricklayer	33	4.7	29	4.0
	Carpenter	55	7.9	53	7.4
	Electrician	82	11.7	75	10.4
	Landscaper	20	2.9	24	3.3
	Mechanic	73	10.5	58	8.1
	Painter	16	2.3	21	2.9
	Plumber	43	6.2	44	6.1
	Plant operator	64	9.2	64	8.9
	Plasterer	21	3.0	27	3.8
	Roofer	10	1.4	10	1.4
	Supervisor	42	6.0	43	6.0
	Steel worker	6	0.9	12	1.7
	Unskilled worker	160	22.9	173	24.0
	Other	44	6.3	55	7.6

Rameezdeen & Elmualim, 2017

Fig. 2.9 shows that, although workers in the Civil Engineering sub-sector experienced more injury than the building sub-sector, unskilled workers were equally exposed to a lot of injury due to heat stress. Construction workers belonging to small and medium sized companies were likely to suffer more accidents and injuries during the heat wave period (Rameezdeen & Elmualim, 2017). The number of accidents that was reprted during the heat wave was less than non-heat wave periods. This suggested that some measures to mitigate the effects of the heat waves could have been taken by the contractors.

Unions also play a major role to combat heat stress. In Australia, construction workers through their Master Builders Association resorted to a common procedure of work to mitigate excessive heat stress at the onset of work and during heat waves. According to the agreement, work areas in a site were divided into three categories below:

- Areas which are exposed to direct heat such as outdoor in the open and work platforms. These can be considered areas affected by ambient heat
- Less exposed areas which are shaded such as lower levels of multi-storey buildings or basements
- Areas which are air-conditioned.

Arbury et al. (2014) studied OSHA federal enforcement cases which indicated 20 cases of heat related illness or death among workers. In most of these cases, employers had no program to prevent heat illness or the program was deficient and most of the workers affected were working in an outdoor area and carrying out heavy or moderate work. Worker acclimatization was an element most commonly missing and evidently related to worker death (Arbury, et al., 2014). Deaths related to heat occurred mostly in jobs which workers are performing in environments which are hot. This resulted in them generating metabolic heat faster than their bodies can cool down. Recommended preventions on heat stress on workers include the provision of water, rest breaks in a shaded area and a cool area for employees. Arbury et al. (2014) recommends that acclimatization of workers is an essential element and should be included in programs that are dedicated to worker heat stress prevention.

2.17 Overview of Occupational Practices Carried out by Construction Workers in Kenya

The slab casting stage in Kenya is mainly undertaken by informal construction workers and normally completed within a day. These workers are commonly known as casual workers in Kenya and are attributed as unskilled workers. Construction workers undertaking concreting are required to work until the task is completed. This can be a few hours to longer hours which is more than the 8 hours commonly undertaken. Mitulla & Wachira (2003) who studied informal labour in the construction industry in noted that sometimes construction workers increased the number of working hours per day, particularly when the tasks being carried out had to completed on the same day, for example concreting. They noted that construction workers had access to machine methods such as mixers and poker vibrators occasionally but often have to do without them. They recommended the need to devise a means of enforcing the occupational health regulations in informal construction operations in order to reduce workplace hazards exposure.

Another study by Ebole (2005) indicated that extension of working hours for concreting works was prevalent on both formal and informal sites at 55% and 62% respectively. To further aggravate the matter, these concreting jobs are physically demanding. Ebole (2005) found out that the majority of the informal sites (67%) delivered their concrete into position manually. This means that construction workers had to manually carry the mixed concrete using wheelbarrows or buckets to the pouring destination. During manual slab construction, construction workers are divided into groups with specific duties. These groups include the loaders, the distributers, and the machine operators.

Table 2.2: Casual construction workers undertaking concreting

Loaders	**Distributers**	**Machine Operators**
Sand Loader	Concrete Distributer	Concrete mixer Operator
Ballast Loader		Vibrator Operator
Water Loader		Hoist Operator
Cement Loader		

Source: Author, 2022

The sand loader loads fine aggregates into the concrete mixer while the ballast loader loads course aggregates into the concrete mixer. The water and cement loaders load water and cement respectively. Concrete distributers carry freshly mixed concrete to the location where the slab is constructed. The concrete mixer operator operates the concrete mixing machine while the vibrator and hoist operators operate the porker vibrator and hoist machine respectively. Occupational hazards that may result into heat stress include physical exertion due to the workload involved and continuous exposure to direct sun outdoors. The conditions may further be aggravated if workers wear PPE's that are not favorable for hot and humid environments.

A study on the evaluation of PPE utilization among construction workers in Mombasa County by Muema (2016) found that construction workers were aware of hazards, injuries and illnesses associated with construction work. 80% of construction workers had suffered illness or injuries in the course of their duties but 50% did not wear PPE's. Construction workers took their own measures such as clothing type to combat heat stress. Wearing of light clothes in strenuous activities was observed. Ndegwa, (2017) who studied labour productivity and performance of building projects recommended that greater use of mechanical labour was encouraged.

2.18 Study Gaps

hIt is well known that the exposure to heat from hot or warm and humid environments is detrimental for workers because of heat stress. These can result in heat related illnesses or even death. At the hot and humid environment of Mombasa, there has been growing concern in the construction industry in terms of improving productivity for construction workers. Lamka (2015) investigated factors influencing construction labour productivity. The study recommended that policy makers should enhance project scheduling and put in place strategic management structure that can enhance labour productivity. Many authors in Kenya have studied issues regarding construction workers productivity and accidents on site affecting construction workers but have not looked at the influence of the prevailing environmental conditions affecting the performance of these workers.

the construction industry is known to be driven by productivity and targets such as completion dates and therefore heat stress prevention measures are not high in the priority lists of contractors and not enforced on construction sites but plays a major role in the overall performance of a project. It is well known that environmental conditions affect productivity, injuries and accidents on site and the health of workers. While studying the various ways of improving productivity of a project and reducing accidents on site, researchers should also look at environmental conditions such as heat, which could be the underlying cause of reduction in productivity and an increase in accidents on site and not the carelessness of workers and the often blamed poor planning by construction managers. There being a gap in research in the country concerning construction in hot and humid environments, the research assessed the on-site conditions that normally are neglected but affect the overall performance of the project. Most studies including OSHA discuss heat stress based on the strenuous nature of the work that is whether heavy moderate or light in relation to heat exposure, few studies have compared duration of exposure in relation to heat exposure which this study has endeavored to take into consideration.

2.19 Occupational Health Regulations Related to Heat Stress

In Australia, regulations concerning health and safety and codes of conduct identify the effects of thermal stress on the safety and health of workers. Safe Work Australia recommended an ambient temperature of 20 ° C to 26 ° C in 2011 to provide optimal thermal comfort for workers (Rameezdeen & Elmualim, 2017). According to Chavkin (2015), Costa Rica in the year 2015, came up with a legislation that required employers of workers in the agricultural sector who labour outdoors in the open to provide shade in the work premises, make water available ,work-rest breaks, and protective clothing (Acharya et al., 2018). The legislation was based on the United States, OSHA heat index levels guidelines that protect workers so as to offer protections as the heat increases (OSHA. US, 2020). The reason for passing this law was the result of an increase in epidemics including a chronic kidney disease associated with occupational thermal stress and chronic dehydration among Costa Rican workers. (Acharya et al., 2018).

In Nicaragua and El Salvador, the thermal stress law did not specifically apply to construction workers, but later it was specifically applied to them. In the global scene, the heat-related construction worker law is the only understandable and enforceable law implemented at the national level to protect a subset of outdoor workers from heart rate disorders (HRI). (Acharya et al., (2018) The United Arab Emirates (UAE) have taken steps to protect workers working outdoors from heat stress, but those steps are unlikely to be adequately implemented. This period of July and August was later changed from 12:30 pm to 3:00 pm by a construction contractor's push to increase working hours during overheating (Acharya et al., 2018).

2.20 Occupational Health Regulations Related to Heat Stress in Kenya

OSHA regulations in Kenya talk about physical hazards. These hazards include extreme temperature, pressure, noise, vibration, and radiation. However, it is not clear where the extreme temperatures come from, whether environmental or artificial. OSHA in Kenya has not yet identified environmental issues that affect construction workers, such as thermal stress. All contractors are required to undergo safety training as part of their contractual obligations (OSHA, Kenya, 2007). Occupational accidents are accidents that result in or are related to the employment of employees and cause personal injury. The types of occupational accidents and illnesses are considered to be consistent with the ILO Code of Conduct. Construction workers who perform prefabricated work are commonly referred to as temporary workers. According to the ILO's National Profile on Occupational Safety and Health in Kenya, those who are casually employed and are not employed for the employer's business purposes are not considered employees (ILO, 2013). According to the report, outdoor heat stress does not appear in the list of dangerous happenings in Kenya's 2007 OSHA first schedule

According to the draft of the Kenya Ministry of Health's Basic Occupational Safety and Health Training Manual (2015), physical danger is a situation or situation that causes physical injury or severe stress. This is either natural and / or artificial. Examples include extreme pressure and temperature, noise, vibration and radiation (ionizing and non-ionizing). These can harm workers if not properly controlled. The Ministry of Health's draft health and safety training manual recognizes thermal conditions as a mode of exposure to and points out that thermal stress can be caused by abnormally high temperatures and humidity, or radiant heat. The effects of exposure to themal stress are as follows: heat stroke, heat exhaustion, heat rash, febrile seizures, decreased morale, decreased concentration.

The Ministry of Health of Kenya (2015) discusses extreme temperatures. This indicates that very high or very low temperatures can be harmful to your health. The manual defines exposure to extreme heat as heat stress. In addition, heat stress is described as a response to heat stress, which is physiological and behavioral. Prolonged exposure to slightly hot environments can cause discomfort, malaise, irritability, demoralization, increased anxiety, and lack of rest to focus on work. Heat rash, febrile seizures, heat exhaustion, and finally heat stroke can be caused by increased exposure to heat, in descending order of severity. Other problems associated with extreme fever include cataracts and exacerbations of other conditions such as cardiovascular and endocrine disorders. (Ministry of Health, 2015)

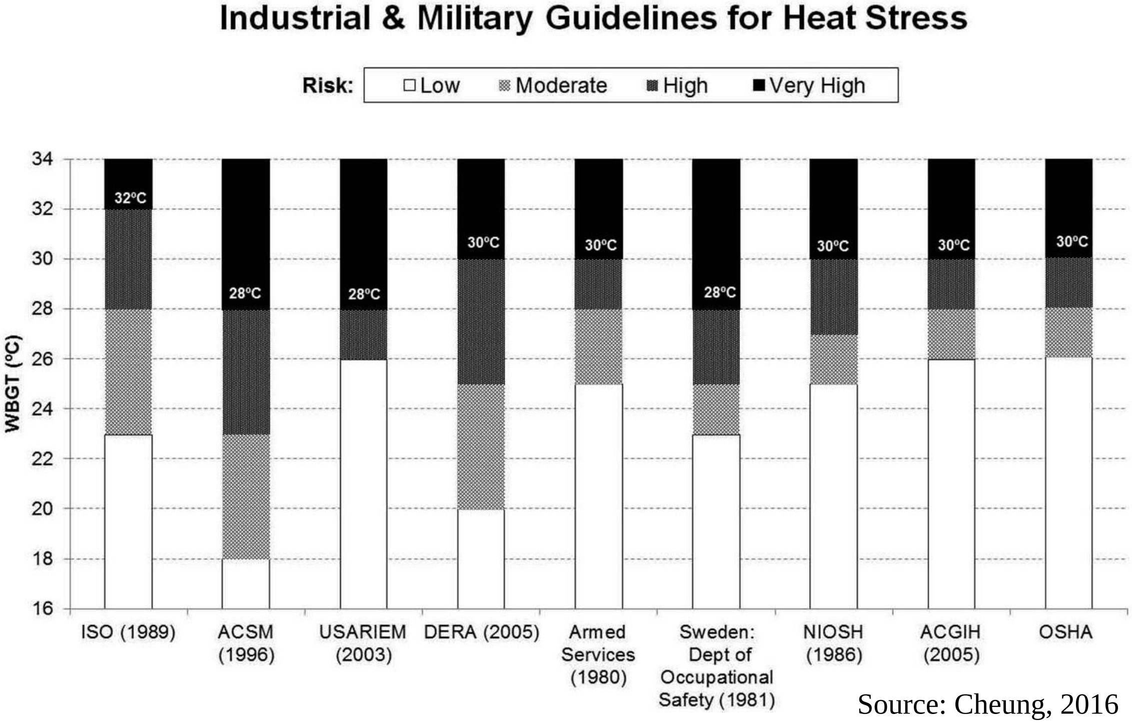
The Ministry of Health (2015) further identifies environmental risks such as global warming and identifies risk assessment as a process of deciding how safe the situation is and assessing risk acceptability. The main purpose of the risk assessment process is to eliminate or reduce the level of risk by adding precautions or controls as required. This leads to a safer and healthier workplace. The method of choice should take into account the associated risks, the number of workers that may be affected, and the size of the entire group. Simple hazards can be evaluated using simple qualitative methods, and complex hazards can be evaluated using quantified or semi-quantified methods. Risk levels can be classified as follows:

Not significant: acceptable risk. No further action required
Low : An acceptable risk, but looking for opportunities for improvement
Medium : Improve risk management measures within 3 months
High : Shut down and improve immediately

(Adapted from Ministry of Health Kenya, 2015)

2.21 Heat Stress Standards and Guidelines

Figure 2.10: Industry and Military Guidelines for Heat Stress



Source: Cheung, 2016

International bodies dealing with work-related thermal stress on workers regularly develop thermal stress guidelines that set upper limits for safe thermal stress levels. Figure 2.10 provides a summary of WBGT thresholds recommended for heat-related illnesses at very high, high, moderate, and low risk from various international organizations.

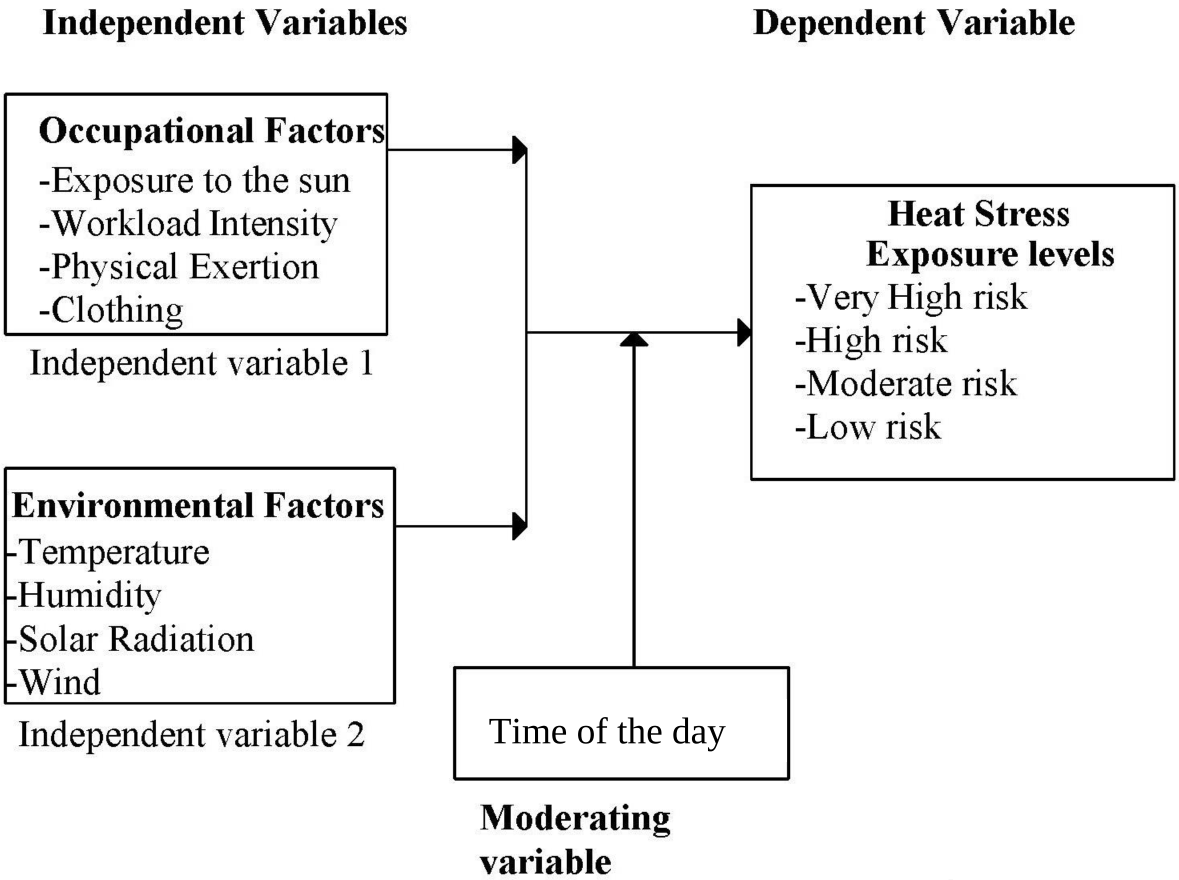
These organizations are: American Conference of Governmental Industrial Health (ACGIH); American College of Sports Medicine (ACSM); Defense Assessment Research Institute (DERA); National Institute of Occupational Safety and Health (NIOSH); Occupational Safety and Health Administration (OSHA); US Army Environmental Medicine Research Place (USARIEM). The upper limit for ISO 7243 is 32 ° C and the lower limit for ACSM is 18 ° C. All moderate working limits are between the WBGT values of 23 ° C and 28 ° C.

ISO7243, 1989, cited in Cheung 2016, states that the WBGT limit for workers who are acclimatized and exposed to physical stress is that the WBGT threshold of 28 ° C is applied to moderate workloads and of 25 ° C. It states that it suggests that WBGT applies to heavy workloads. Air Velocity

NIOSH estimates the limits of non-adapted and adapted workers. The recommended alarm limits are used for non-acclimatized workers and the recommended exposure limits are used for acclimatized workers. Example: An acclimatized worker who consumes 349 W for 45 minutes of work has an hourly WBGT limit of 27.5 ° C and a WBGT limit of 28.5 ° C if the work time is 30 minutes. Means. The OSHA Standards Advisory Board on Heat Stress recommends WBGT limits of 30 ° C, 27.8 ° C, and 26.1 ° C, respectively, for light (349) workloads (cited in Ramsey, 1975, Cheung 2016).). ACGIH has developed a threshold (TLV) that defines the maximum allowable limit for heat exposure (cited in ACGIH, 2005, Cheung 2016). The TLV range is 30 ° C for light work, 26.7 ° C for medium work, and 25 ° C for heavy work, which is the limit of the WBGT. Keep in mind that heat exposure guidelines and standards are common and need to be modified based on the specific context of the intended application. For this study, we selected ACGIH guidelines that include screening tools that may be effective for this type of study. ACGIH's screening criteria are accurate and easy to follow.

2.22 Conceptual Framework

Figure 2.11: Conceptual Framework



Source: Author, 2022

The independent variables of the study included Occupational factors measured in terms of construction worker exposure duration to the sun, their perceived workload intensity, physical exertion and clothing worn while working. The second independent variable included Environmental factors measured in terms of temperature, humidity, wind effect and solar radiation. The Dependent variable is the Heat Stress exposure level which is measured in terms of being Very high and dangerous to the workers, high, moderate and low risk. The moderating variable was the time of the day the activity was being carried out by construction workers. Time was categorized into 5 sessions which are; 8 – 10am, 10 – 12am, 12 – 2pm, 2 – 4pm and 4 – 6pm. The study hypothesized in the alternate, that construction workers are significantly affected by the levels of heat stress in Mombasa during daytime work due to the warm and humid environmental conditions.

2.23 Conclusion

The literature reviewed in this chapter covered; heat stress, assessment of heat stress and heat exposure. A conceptual framework was then developed to represent the relationship between occupational and environmental exposure and heat stress levels. Out of the literature reviewed, the study also identified the following gaps; lack of local guidelines by the OSHA Kenya on workers who work in the open sun in hot and humid environments. Literature on heat stress on construction workers in Kenya was also minimal. However, the study found literature from other countries with similar environmental conditions that have identified these concerns and generated guidelines on how to deal with heat stress exposure on construction workers.

Literature on industry standards and guidelines on heat stress and past studies on heat stress affecting construction workers were reviewed. Apart from the industry guidelines, the study found out that the US military also developed their own guidelines with similarities to the industry guidelines based on WBGT because soldiers like construction workers are frequently exposed to the direct sun. Literature on common practices in concrete construction was also covered. This enabled the study to shed light into local manual practices undertaken by construction workers in construction of buildings the Kenya. The literature review identified how WBGT can be measured and heat levels identified. Furthermore it looked at existing international standards based on WBGT on occupational heat stress and came to a conclusion that WBGT is a reliable standard in measuring heat stress levels for hot and humid environments such as those conditions experienced in Mombasa. The study noted that while setting heat stress standards is important, enforcing heat stress regulations can be challenging. The next chapter presents the research methodology that was adopted by the study to address the pre-set research questions and hypothesis within the confines of related past literature as covered in this chapter

CHAPTER THREE

RESEARCH METHODOLOGY

3.1 Introduction

This chapter outlines the procedure, including the associated rationale and assumptions, adopted in studying the research problem and presents the methodology that was used in data collection and analysis of the study including; research design, location of the study, population of the study, sampling procedures and sample size, research instruments, data collection procedures, unit of analysis, unit of observation, data analysis, validity and reliability of research instruments and ethical considerations. The research design in this study describes the general approach used to execute the study from inception to completion. The target population, sampling frame and units for the study were defined followed by sample size computation and adjustment for non-participation of construction workers in the study. Data collection approaches and research instruments including their reliability and validity was discussed. The unit of analysis and unit of observation were then clearly defined and lastly the rules and guidelines that governed the conduct of the researcher and research assistants in the course of collecting data for this study was outlined. The chapter concludes with a brief summary of all discussed issues.

3.2 Research Design

Research design is a strategic frame-work for action that serves as a connection between research questions and implementation of the research strategy (Dixon et al., 2005). In other words, it is the process that the researcher follows from inception to completion of the study. The research design discusses to the overall approach that the research chooses in order to incorporate the different components of the study in a comprehensible and rational way making sure that the research problem will be addressed. It can therefore be referred as a scheme for the procedure of gathering, measurement and analyzing the data collected (Sacred Heart University Library, 2020). The study began by reviewing previous literature relevant for this research to get an in-depth understanding of heat stress in hot and humid environments. Based on the approaches to methodologies studied in other related research papers, the researcher opted for a field study through walk-through surveys of construction sites in Mombasa County which were both qualitative and quantitative. It was imperative that the field survey study would enable the researcher to observe construction workers activities in their working environment and collect qualitative data such as clothing worn, worker occupational activities such as workloads and exertion levels. The study also collected quantitative data through recording of environmental measurements at construction sites including Wet Bulb, Dry Bulb and Globe Temperature (WBGT).

To assess occupational factors affecting construction workers that are related to heat stress, the research employed descriptive walk through surveys at construction sites in Mombasa County where construction workers were studied. The aim was to observe and classify construction workers based on their activities on a construction site using ACGIH guidelines. The construction workers job description, work activities and duration of exposure to direct sun-light were recorded.

To measure the heat levels of construction sites in hot and humid environments, this study employed a quantitative research approach to gather the data related to environmental parameters. The measurements were based on WBGT parameters which include air temperature, humidity, solar radiation and wind chill. The quantitative environmental data collected was used to test the hypothesis that states, ‘construction workers are significantly affected by the levels of heat stress in Mombasa during daytime work due to the warm and humid environmental conditions.’

$$WBGT_{outdoor} = (0.7 \times Tnwb) + (0.2 \times Tg) + (0.1 \times Tdb)$$

Where:

Tnwb : Natural Wet-Bulb Temperature

Tg : Globe temperature

Tdb : Dry-Bulb air Temperature

Source: NIOSH (2016)

To assess heat stress risk on construction workers, the study compared WBGT environmental measurements measured, with the work limit TLV’s to find out the level of heat stress according to ACGIH guidelines. The study further investigated the WBGT heat stress threshold limits for construction workers in Mombasa based on their activities on site. Humidex Index values were compared to the Humidex table.

3.3 Research Method

Research methods are basically the techniques that are used to acquire research data. There are two research methods available in the field of social science: Qualitative and Quantitative research methods. Rubin & Babbie (2010) defines Qualitative design as “a research design method involving a realistic and informative approach, whose findings don’t arise from statistical measures or other means of quantification.” Heppner et al. (2008) indicated that qualitative study uses data to arrive at conclusions rather than as a source of validation for a theory described while, Aliaga & Gunderson (2002) describe quantitative research as “an inquiry in explaining phenomenon through the collection of numerical data that are examined using mathematically based methods such as statistics.” In this research, a cross-sectional descriptive & quantitative approach through walk-through surveys was preferred because the aim was to provide an accurate description of the event using empirical data. The event being construction workers manually carrying out construction work in a warm and humid environment. The research was an observational analytic study. This involved observing construction workers activities on construction site in a warm and humid environment, and at the same time recording environmental measurements to determine the heat stress risk using ACGIH guidelines. A field study was conducted whereby observations were undertaken, and thermal environment measurements recorded. The independent variables were thermal environment factors and occupational factors while the dependent variable was the levels of heat stress.

3.4 Target Population

Target population is the aggregate of all persons and items that conform to a given specification (Mugenda, 2003). The target population in research is also as the group of persons to which the findings of a study may be generalized. The research set a specification of the target population as construction workers in active formal building construction sites in the warm and humid construction sites. The research set a specification of the study population as construction workers at construction sites around Mombasa County working on residential construction projects. The study population is therefore fully described as follows:

- Construction workers undertaking their job in active construction sites in Mombasa

- The stage of construction is at super-structure level where construction works such as steel bar reinforcement works and slab casting are undertaken. Literature reviewed indicates that steel reinforcement bar works and slab casting works are some of the most labour intensive and time consuming activities on a construction site because they are normally undertaken in the open sun.
- The construction site is in the warm and humid environment of Mombasa.
- Residential projects of not more than four storeys high where the likelihood of using manual labour and less machinery was anticipated for uniformity purposes.

The study aimed to assess the levels of heat stress exposure on construction workers in building construction sites in Mombasa hence the researcher considered only active construction sites that had registered their projects with the NCA. However, due to the expansiveness of the geographical area of study and time limitations, the study identified active construction sites located in Mombasa County through a preliminary study conducted in Changamwe, Jomvu, Kisauni, Likoni, Mvita and Nyali Constituencies to identify and record the number of active construction sites in Mombasa County that met the population specification. The results are shown in table 3.1 below.

Table 3.1: Population Distribution in six Sub-Counties of Mombasa

Location of the site	**Number of Active construction sites**	**Total Number of workers**
Changamwe	76	1454
Jomvu	61	1069
Kisauni	33	708
Likoni	37	795
Mvita	48	1380
Nyali	39	609
Total	**294**	**6015**

Source: Field study, 2022

Table 3.1 shows the number of residential projects undergoing construction which constituted of Two hundred and ninety four (294) active formal building construction sites in Mombasa County. The work undertaken at these sites was mostly manual with less use of machinery which is commonly undertaken by the smaller contractors such as NCA 7 and 8 because this is the most vulnerable group in relation to heat stress issues. The study population of construction workers was six thousand and fifteen (6015).

3.4.1 Sample Frame and Sampling Units

A sample frame is a list containing all sampling units. It is therefore consists of a list of items from which the sample is to be drawn (Kabir, 2016). A sample frame is also a subset of the population that the researcher has access to. A sample unit is a basic unit that comprises of a single element or group of elements of the population to be sampled. A sampling unit selected is dependent on the sampling frame (Kabir, 2016). The units of analysis from the construction sites identified were therefore construction workers undertaking construction work in Mombasa. Workers were of all 18 years and above. Both genders were identified. Acclimatized and non-acclimatized workers were also identified for the study. The construction workers whose job description identified for the research included:

- Steel Reinforcement works – bending and fixing slab steel reinforcement bars
- Walling – Construction of walling prior to slab casting or roofing works
- Form work construction – Prepares formwork for slab casting and monitors formwork during slab casting
- Concreting – Involves mixing concrete materials and casting the concrete on either a slab, beam or column
- Plumbing and electrical works – The plumber/electrician monitors and modifies plumbing/electrical installations respectively during slab casting.
- Roofing works – Fixes roofing materials mostly in the open sun

3.5 Sampling Technique

Probability sampling is a sampling technique whereby the researcher chooses samples from a greater population size using methods that are based on probability theory. (QuestionPro, 2021) In probability sampling each unit in the population has a known non-zero chance of being picked through the use of a random selection procedure such as simple random sampling. Stratified sampling was used in the study. Stratified sampling involves dividing the population into sub-categories or strata where samples are drawn at random. (Kabir, 2016). Stratified sampling involved dividing the targeted population into sub categories/strata. This technique is frequently used in survey studies as it presents the advantage over completely random sampling by ensuring that all groups of interest to the researcher are sufficiently represented. These sub-categories were based on the specific work performed by the construction workers in a construction site. The sub-categories included Steel Reinforcement works, Walling, Form work construction, Concreting, Plumbing and electrical works and Roofing works.

3.5.1 Sampling Procedure & Sampling Size

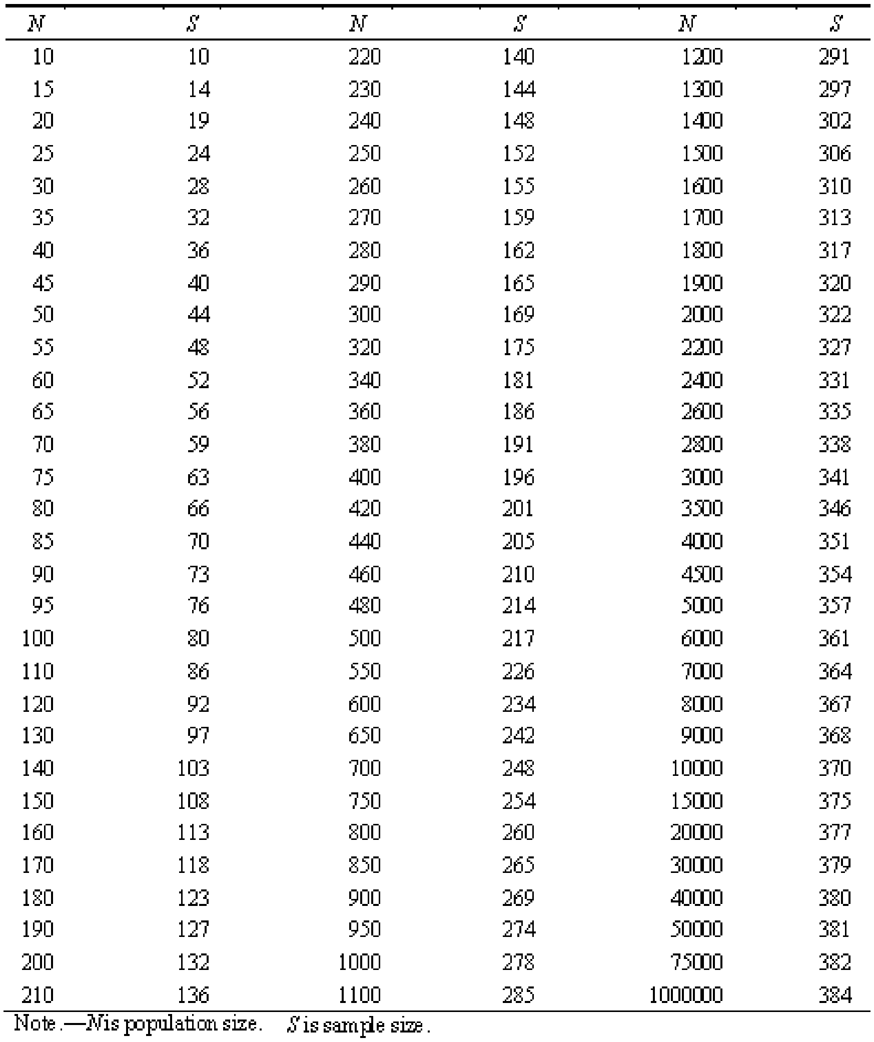
Sampling Procedure

The study applied Stratified Random sampling which involved a dividing the population sample frame into everal sub-categories. Only projects that had received approvals from the NCA were considered. The NCA has mandatory requirements for construction projects to be registered by them which include, approved plans by the County Council, NEMA approvals and registered construction consultants. It was noted that larger sites preferred to use machinery for slab casting rather than manual labour. Smaller sites constructing residential units and apartments less than four storeys preferred the use of construction workers to undertake manual work. Construction firms were identified in 6 constituencies of Mombasa County that met the criteria. This ensured that each Constituency was a represented. The numbers of construction workers at these construction workers were then recorded as the sample frame from which the sample unit was constituted as indicated in Table 3.1.

Sample Size

To determine the sample size in this study, a confidence level of 95% of the target population was assumed and the formulae as devised by Krejcie (1970) was applied to achieve the required sample size. Simple random sampling was used in the study to obtain a representative sample. The 6015 construction workers were divided into 6 strata/ sub-categories and a sample picked from each stratum. Krejcie & Morgan (1970) table below provides a simplified method to identify sample sizes.

Figure 3.1: Krejcie & Morgan (1970) table



N	*S*	*N*	*S*	*N*	*S*
10	10	220	140	1200	291
15	14	230	144	1300	297
20	19	240	148	1400	302
25	24	250	152	1500	306
30	28	260	155	1600	310
35	32	270	159	1700	313
40	36	280	162	1800	317
45	40	290	165	1900	320
50	44	300	169	2000	322
55	48	320	175	2200	327
60	52	340	181	2400	331
65	56	360	186	2600	335
70	59	380	191	2800	338
75	63	400	196	3000	341
80	66	420	201	3500	346
85	70	440	205	4000	351
90	73	460	210	4500	354
95	76	480	214	5000	357
100	80	500	217	6000	361
110	86	550	226	7000	364
120	92	600	234	8000	367
130	97	650	242	9000	368
140	103	700	248	10000	370
150	108	750	254	15000	375
160	113	800	260	20000	377
170	118	850	265	30000	379
180	123	900	269	40000	380
190	127	950	274	50000	381
200	132	1000	278	75000	382
210	136	1100	285	1000000	384

Note.—*N* is population size. *S* is sample size.

Source: Krejcie & Morgan (1970)

The table is constructed using the following formula:

$s = X^2 NP(1 - P) \div d^2 (N - 1) + X^2 P(1 - P)$

Where:

s = desired sample size

N = Target population

p = population proportion (0.5 at 95% confidence level)

q = 1-p

d = degree of accuracy reflected by the amount of error that can be tolerated at 95% confidence level

X^2 = the chi-square table value for one degree of freedom relative to the desired level of confidence ($X^2 = 3.841$ at 95% confidence level

Table 3.2: Sample distribution per job group

Job Group/Description	Target population	Sample construction workers
Steel reinforcement works	699	42
Walling	836	51
Formwork construction	974	59
Concreting works	2703	163
Plumbing & electrical works	425	26
Roofing works (pitched roof)	378	23
Total	**6015**	**364**

Source: Field study, 2022

Sampling error adjustment

To minimize the sampling error a large sample of the accessible target population is desirable. According to Israel (1992), the practice by many researchers is to add 10% to the sample size to compensate for persons that do not wish to participate in the research. The sample size, also on regular basis, is increased by a maximum of 30% to compensate for non-participation. Thus, the final number of walk-through surveys can be considerably larger than the number required for a desired level of confidence and sampling error. The study relied on construction firms to give access to construction workers who are actively carrying out construction work. The study therefore added 30% to the sample size to cater for respondents that would voluntarily opt not to participate in the study. This brought the sample size to Four hundred and seventy five (475) construction workers at formal building construction sites. Table 3.3 shows the final total number of construction workers to be sampled across Mombasa.

Table 3.3: Sample adjustment distribution per job group

Job Group/Description	Sample	Sample adjustment
Steel reinforcement works	42	55
Walling	51	67
Formwork construction	59	77
Concreting works	163	212
Plumbing & electrical works	26	34
Roofing works (pitched roof)	23	30
Total	**364**	**475**

Source: Field study, 2022

3.6 Research Instruments

A research instrument is a tool that is used to collect, measure and analyze data related to a study. For field studies, the research instrument used was the WBGT. WBGT is considered to be the most widely accepted and used method for measuring environmental variables on Occupational heat stress. Measurements were taken using a Wet and Dry bulb thermometer whose model is SK-RHG skSATO made in Japan. For radiant heat measurements a globe whose diameter is 150mm/ 6inch was used. The 150mm/ 6inch globe thermometer is regarded as a standard in the Industry as ISO 7243 2008. The WBGT is a temperature that combines effects of ambient temperature, RH, wind chill and solar radiation. The research employed the use of a WBGT Index using ACGIH guidelines which allow for the estimation of workers metabolic rates using the observation method. The study employed WBGT measurements through Field surveys and non-participant observations. Non-participant observations involved observing construction workers at their working environment in a construction site with limited interference. It involves watching what people do which is a type of correlational (non-experimental) method where the researcher observes ongoing behavior (QuestionPro, 2021).

N3.6.1 Validity and Reliability of Research Instruments

Validity refers to the level to which an instrument measures what it is intended to measure (Kathuri & Pals, 1983) In order for an instrument to be valid, it shoild cover the content of the research. An instrument therefore can be valid if it is consistent and reliable when constantly produces the same results after being applied severally to the same group of subjects. Yi & Chan (2017) revealed that WBGT has the highest validity in forecasting the impacts of Occupational heat exposure in the construction industry. WBGT is the recommended standard for assessing environmental heat stress and it is suitable for a fixed site such as that of a construction site rather than a movable one. The WBGT is included in (ISO 7243) and ACGIH 2009) standards since it was developed in the 1950s by the US Army (Yaglou & Minard, 1957). The WBGT has been recognized by a number of agencies such as ACGIH and NIOSH as safety Index to set limits in Industrial workplaces (Yi & Chan, 2017).

The non-participant observations sacrifices internal for ecological validity and therefore has minimal or no interference and hence mimics real world scenarios. Ecological validity examines whether the results of a study can be generalized to real-life settings. This indicates a very high validity and reliability. The researcher used observation forms to actively record the ongoing activities being investigated. 12 research assistance distributed in the 6 sub-counties of Mombasa were trained by the researcher in purpose, intended benefits and use of research instruments while maintaining anonymity and confidentiality.

The research employed the use of ACGIH screening criteria for heat exposure as follows: Light, Moderate, Heavy and Very Heavy which classifies workload and evaluates whether heat stress situation exists. The study also employed the use of Borg CR10 scale of perceived exertion with a rating of 0 – 10 with 0 indicating rest, 1 - very easy, 3 - moderate, 5 - hard and 10 - maximal. The study also took into consideration the duration of exposure. The Borg Rating of psychophysical bases of perceived exertion (RPE) scale, developed by Swedish researcher Gunnar Borg who studied psychophysical bases of perceived exertion in 1982, is a tool for measuring an individual’s effort and exertion,. It also measures fatigue and breathlessness during physical work and therefore it is highly relevant for Occupational health and safety practices. In its simplest form, it provides a measure of how hard it feels when the body is working. These are based on physical sensations that the subject experiences, including an increase in heart rate, sweating and muscle fatigue. (Williams, 2017).

3.8 Unit of Analysis and Unit of Observation

Unit of Analysis

The unit of analysis defines what the study is focusing on (what the case is), such as an individual, a group, an organization, a city and so forth (Berg, 2001). Construction workers working at construction sites were the unit of analysis under a warm and humid environment of Mombasa. The key items in the study were the length of time (duration) a construction worker is exposed to heat in the open while working in relation to the level of temperature (WBGT) in the environment recorded at the construction site during the field study.

Unit of Observation

Babbie (2013) indicates that there are specific study elements from which data used for analysis is collected and these are known as units of observation. The units of observation are therefore the thermal environment of construction sites and occupational parameters that affect construction workers.

3.9 Data Collection Procedure

After approval of the study proposal by the University of Nairobi, researcher obtained an authorization letter to collect data from the field. The researcher employed a research assistant in the collection of data in the field survey study. Construction workers consent was sought through the foreman/construction manager and their participation was voluntary. Before the study was conducted, a pre-study data collection sheet was filled with the assistance of the researcher (See Appendix III).

To assess occupational factors affecting construction workers that are related to heat stress on site during slab construction, the study employed walk through surveys to observe and describe construction workers undertaking construction work in their uninterrupted ‘natural setting’ on site. The construction workers job description, work activities and duration of exposure to direct sun-light was recorded (See Appendix IV).

To measure the heat levels of a construction site, this study employed a quantitative research approach to gather the data related to environmental parameters. (See Appendix V) The measurements were based on WBGT parameters which include air temperature, humidity and solar radiation and wind chill. The WBGT formula below for outdoor measurements was used.

$$WBGT_{outdoor} = (0.7 \times Tnwb) + (0.2 \times Tg) + (0.1 \times Tdb)$$

Where:

Tnwb : Natural Wet-Bulb Temperature
Tg : Globe temperature
Tdb : Dry-Bulb air Temperature

Source: NIOSH (2016)

To assess heat stress risk on construction workers, the study compared environmental measurements measured, with the WBGT index and Humidex index charts to find out the level of heat stress. Exposure durations and recorded temperatures were also recorded to understand the severity of the results.

3.10 Data Analysis and Presentation

The study used the quantitative method of data analysis. The analysis was done with the help of Microsoft Office Excel 2010. This is a spreadsheet software program. The ONE-Way ANOVA test was used to understand the comparisons and associations between variables used to analyze the heat exposure levels on construction workers. The indices used for data analysis in this study were the WBGT Index and the Humidex Index. The statistical methods used for data analysis included Tables, bar charts, box and whisker plots and Graphs. These were drawn for ease of interpretation and understanding. To analyze data by the ordinal scale, an Average index (AI) was calculated to determine the ranking risk of variables.

3.11 Ethical Considerations

Scientific research work is governed social values which involves individuals and the community at large. Research ethics involves protecting the dignity of the subject in disclosing the information collected. Research is an obligation fulfilled for the benefit of the communities in which science and universities serve. This study addressed five general ethical considerations regarding this study.

Justice and credibility

Research adheres to the ethical principles of impartiality and credibility, and when conducting research on humans, animals, or the environment, research responsibilities and obligations should be increased. (University of Pretoria, 2020)

Code of Conduct

Research must always be intellectually authentic, and researchers must always act in a professional way. You must always be able to meet or be influenced by the legal requirements of a particular research project. You must also comply with the rules of research ethics that apply within your university, faculty, and / or discipline.

In addition, it is necessary to comply with the rules of research ethics established by a particular specialty organization within the region regulated by that particular specialty organization, and finally, anything that can be considered scientific misconduct is always You need to refrain from it. (University of Pretoria, 2020)

Confidentiality

All research results should be able to be reviewed by university colleagues, other researchers, stakeholders, and the general public. When privacy is required, researchers must respect it.

Research data may not be used for any purpose other than required or permitted. Researchers need to protect the interests of the university with respect to intellectual property.

Safety

The research will follow the safety protocols set out by the National Construction Authority for construction sites in Kenya. The researcher will make sure that PPE's are worn during the field study on the construction site.

Informed Consent

As a founding principle of research ethics, informed consent will look at the aspect of human beings allowed to join the research voluntarily. All aspects of the study are explained to the construction workers before they voluntarily join the study.

3.12 Conclusions

The study opted for descriptive quantitative approach because the aim was to provide an accurate description of construction workers heat exposure levels at a construction. The target population were construction workers undertaking their job on a construction site and the stage of construction was at super-structure level where construction works such as steel bar reinforcement works, masonry slab casting were undertaken. The construction sites were in a warm and humid environment of Mombasa. The study adopted stratified sampling because of the nature of the research which involved studying different categories of construction workers located in 6 different constituencies in Mombasa. Field survey data for occupational factors was collected using the using observations and WBGT measurements of the environment. The study found that WBGT has the best predictive power to predict the effects of occupational heat exposure in the construction industry. The study employed the use of ACGIH screening criteria for heat exposure, the Borg CR10 scale of perceived exertion with a rating of 0 – 10. The indices used for data analysis in this study were the WBGT Index and the Humidex Index. The statistical methods used for data analysis included Tables and Line charts and Graphs. The analysis and findings are presented in the next chapter.

CHAPTER FOUR

DATA ANALYSIS, PRESENTATION AND INTERPRETATION

4.1 Introduction

This chapter presents the results and findings about the demographics of the study participants, an overview of the data, and the statistical analysis used for the assessment of heat stress exposure on construction workers.

The objectives to be achieved by the reports of the field work included; to assess occupational factors affecting construction workers that are related to heat stress on site during construction, to measure the heat levels of a construction site in a warm and humid environment., to assess heat stress risk on construction workers using the WBGT index and Humidex index. From the preliminary study, 6015 construction workers were identified for the study from which 475 were sampled.

4.2 Background Information on the Construction Workers

Prior to the commencement of the study, a pre-study data sheet (see Appendix III) was administered to the workers. The aim was to capture details of the construction workers that included: age, gender, job description, voluntary participation and clothing worn. The data sheet also recorded whether workers were acclimatized or not. All workers were Kenyans and were the age of 18 and above.

The study employed walk-through field surveys randomly on construction sites selected for the study during the month of January and February 2022 starting from 8am to 6pm. The months of January to March are considered some of the hottest months in Mombasa as studied in the literature review.

4.2.1 Participation Rate of Construction Workers

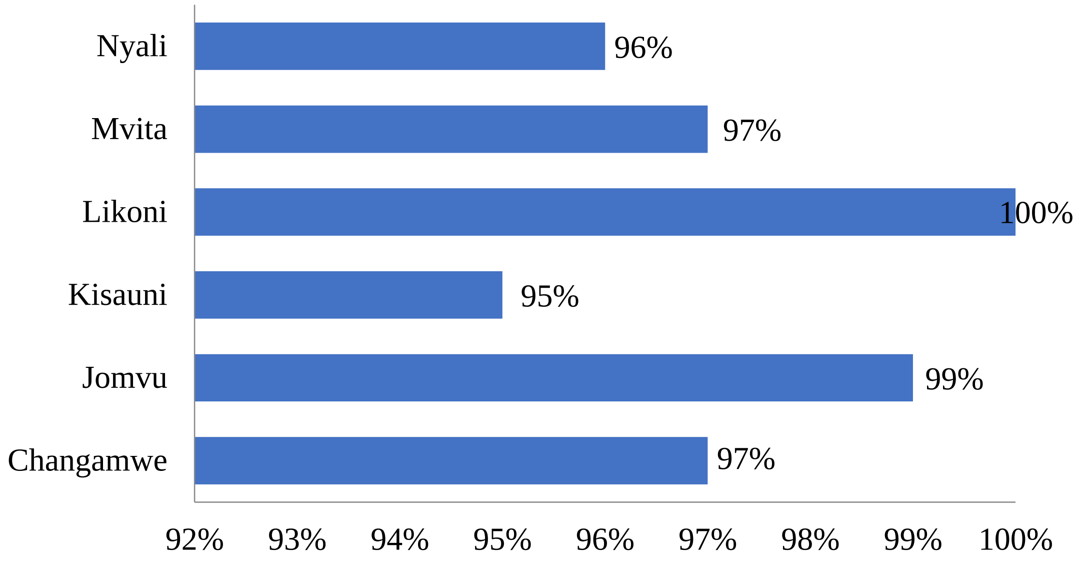
According to Mugenda and Mugenda (2003), a response rate of 50% is enough for analyzing and reporting, 60% is good, while 70% is very good. Table 4.1 shows identified construction workers participation rate of 97 %. This was sufficient for walk-through survey analysis.

Table 4.1: Participation rate of construction workers based on voluntary participation

Location of the site	**Number of Construction workers identified**	**Number of Construction workers that voluntarily participated**	**Participation rate Percentage (%)**
Changamwe	116	113	97%
Jomvu	85	84	99%
Kisauni	57	54	95%
Likoni	61	61	100%
Mvita	107	104	97%
Nyali	49	47	96%
Total	**475**	**463**	**97%**

Source: Field Study, 2022

Figure 4.1: Participation rate of construction workers based on voluntary participation



Source: Field Study, 2022

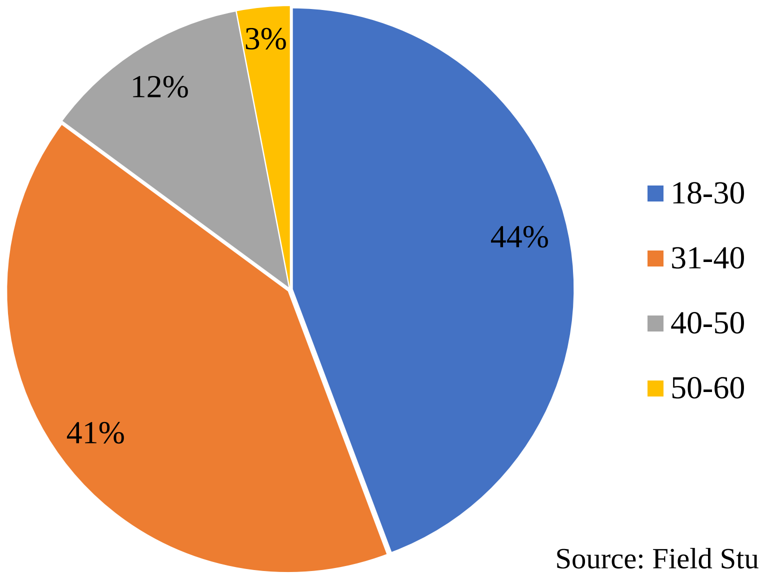
The study was able to measure, observe and record 463 construction workers in 42 construction sites around Mombasa. The construction workers were the unit of analysis in the study and their participation in the study was voluntary. The study attracted immense interest by the construction workers with a 97% voluntary participation rate.

Table 4.2: construction workers based on age in the study

Location of the site	**Number of Construction workers that voluntarily participated**	**Age (years)**			
		18-30	**31-40**	**40-50**	**50-60**
Changamwe	113	59	37	11	6
Jomvu	84	33	44	5	2
Kisauni	54	28	21	4	1
Likoni	61	22	23	15	1
Mvita	104	45	44	11	4
Nyali	47	18	20	9	-
Total	**463**	**205**	**189**	**55**	**14**

Source: Field Study, 2022

Figure 4.2: Construction workers based on age in the study



Source: Field Study, 2022

Construction workers status by age

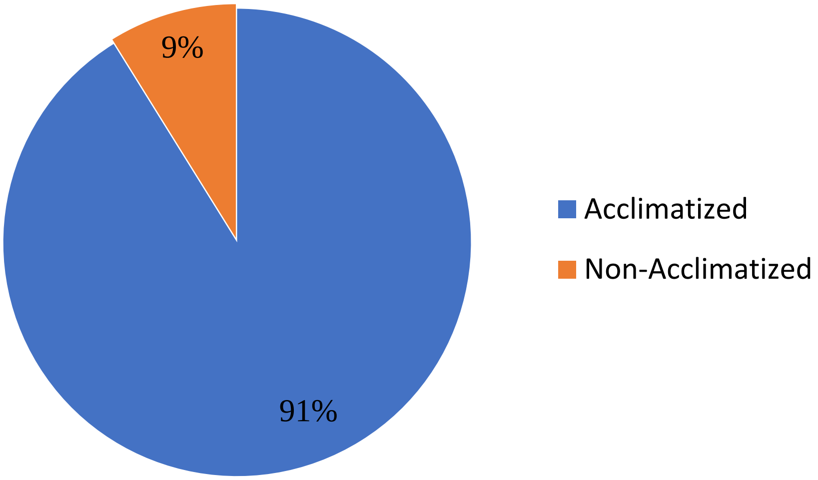
From Table 4.2 and Figure 4.2, the results showed that most of the respondents (44%) were aged between 18-30, 41% were aged between 31-40, and 12% were aged between 41-50. The lowest age category was 51-60 with 3%. The oldest worker was a plumber aged 56 years while several unskilled workers were 18 years of age.

Table 4.3: Number of Acclimatized and Non-Acclimatized workers

Location of the site	**Number of Construction workers that voluntarily participated**	**Acclimatization status**	
		Acclimatized	**Non-Acclimatized**
Changamwe	113	103	10
Jomvu	84	78	6
Kisauni	54	51	3
Likoni	61	52	9
Mvita	104	93	11
Nyali	47	45	2
Total	**463**	**422**	**41**

Source: Field Study, 2022

Figure 4.3: Number of Acclimatized and Non-Acclimatized workers



Source: Field Study, 2022

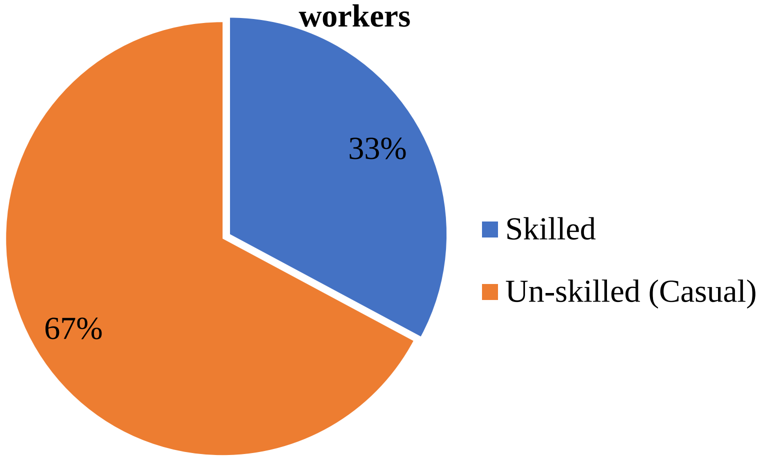
Acclimatization was determined by the period a worker has been working. Workers who had undertaken construction work within a period of two weeks prior to the study were considered acclimatized while non-acclimatized workers had not worked within a period of two weeks or more. Table 4.3 showed that changamwe had the most workers followed by Mvita. The study confirmed that none of the construction sites conducted acclimatization regimens for the workers to increase their tolerance to heat stress. Figure 4.3 indicates a 91% acclimatization rate.

Table 4.4: Number of Skilled and Non-skilled construction workers

Location of the site	**Number of Construction workers that voluntarily participated**	**Skill level**	
		Skilled	**Un-skilled (Casual)**
Changamwe	113	37	76
Jomvu	84	25	59
Kisauni	54	19	35
Likoni	61	21	40
Mvita	104	35	69
Nyali	47	15	32
Total	**463**	**152**	**311**

Source: Field Study, 2022

Figure 4.4: Number of Skilled and Non-skilled construction workers



Source: Field Study, 2022

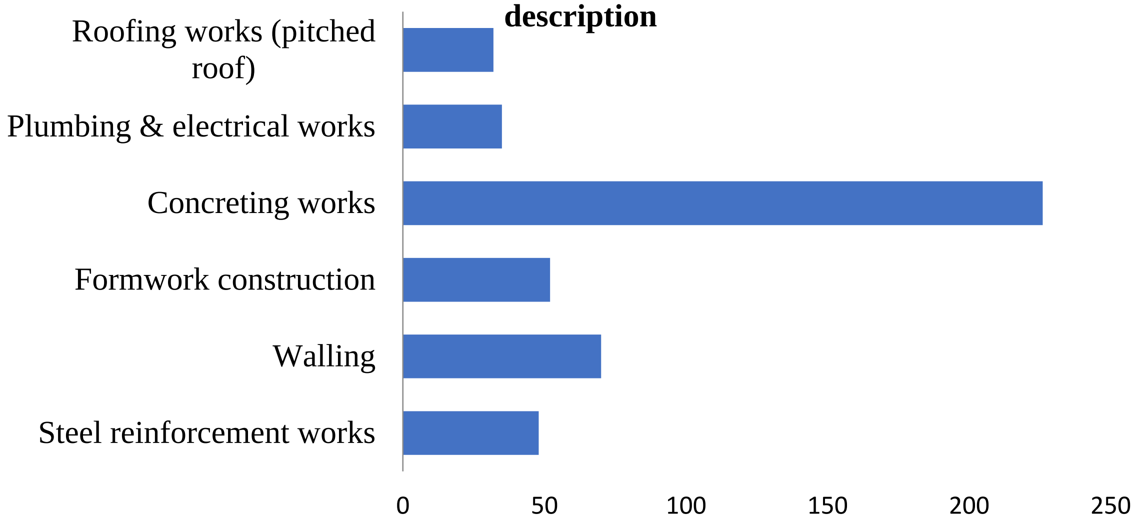
Table 4.4 indicates that unskilled workers were the majority at 311 construction workers. Figure 4.4 shows Un-skilled construction workers formed the most prevalent workers on site at 67%. A third (33%) accounted for skilled construction workers. Unskilled workers also formed the group of construction workers that were exposed to the sun in the open. Their work consisted of assisting skilled workers with materials or equipment when demanded upon them and other strenuous activities such as carrying heavy loads.

Table 4.5: Number of construction workers observed per job description

Job Description	**No. of Construction workers observed**
Steel reinforcement works	48
Walling	70
Formwork construction	52
Concreting works	226
Plumbing & electrical works	35
Roofing works (pitched roof)	32
Total	**463**

Source: Field Study, 2022

Figure 4.5: Number of construction workers observed per job description



Source: Field Study, 2022

Major categories of construction workers observed included Steel reinforcement works Walling Formwork construction Concreting works plumbing & electrical works and Roofing works (pitched roof). Workers undertaking concrete works which included sand loader, mixer operator, hoist operator, ballast loaders and tally manager accounted for most of the workers observed. A total of 226 workers during concreting were observed which accounted to 49% of the workers.

Table 4.6: Construction workers Occupational activity and characteristics

Worker characteristics / Occupational Activity	No. of workers		Age				Gender		Skill category	
	No.	**%**	**18-30**	**31-40**	**41-50**	**51-60**	**Male**	**Female**	**skilled**	**unskilled**
Steel reinforcement works	48	10%	27	15	6	-	45	3	14	34
Walling	70	15%	22	34	11	3	64	6	26	44
Formwork construction	52	11%	26	19	5	2	52	-	24	28
Concreting works	226	49%	110	97	19	-	225	1	53	173
Plumbing & Electrical works	35	8%	10	12	8	5	35	-	21	14
Roofing works (pitched roof)	32	7%	10	12	6	4	32	-	14	18
Summary	**463**		**205**	**189**	**55**	**14**	**453**	**10**	**152**	**311**
%		**100%**	**44%**	**41%**	**12%**	**3%**	**98%**	**2%**	**33%**	**67%**

Source: Field Study, 2022

67% of the workers observed were un-skilled construction workers. According to table 4.6 the majorities of unskilled construction workers were observed during concreting works and were aged between 18-30 years. Male workers were 98% of the workforce observed while most of the workers (85%) were aged between 18-40 years. Only 3 % were aged above 50 years and conducted light construction and supervision works. There were no women observed in formwork construction, plumbing and electrical works and roofing works.

Table 4.7: Acclimatization and clothing status

Worker characteristic / Occupational Activity	**Acclimatization status**		**Clothing**						
			Upper-body clothing				**Lower-body clothing**		**Head gear**
	Acclimatized	**Un-Acclimatized**	**PPE (coverall)***	**T-shirt/ Shirt**	**Vest**	**No upper-body clothing**	**Trousers***	**shorts**	**Helmet**
Steel reinforcement works	45	3	7	22	9	10	48	-	6
Walling	65	5	14	38	11	7	62	8	37
Formwork construction	45	7	8	31	10	3	40	12	44
Concreting works	212	14	8	47	54	117	127	91	21
Plumbing & Electrical works	30	5	7	24	4	-	28	-	27
Roofing works (pitched roof)	25	7	3	25	4	-	29	-	25
	422	**41**	**47**	**187**	**92**	**137**	**352**	**111**	**160**
	91%	**9%**	**10%**	**40%**	**20%**	**30%**	**76%**	**24%**	**35%**

*****workers wore coveralls were not included as part of trousers/shorts category

Source: Field Study, 2022

Table 4.7 above shows 30% of all the workers observed were not wearing upper-body clothing. Of these workers not wearing upper-body clothing, workers undertaking concreting works accounted for 86%. Four of the six job categories had some of the construction workers not wearing upper-body clothing. These were steel reinforcement works, walling, formwork construction and concreting works. It is an indication of the need for evaporative cooling of the body to combat the heat. Another 60% of the workers were wearing T-shirt/ shirt or a vest. 3% of the concreting works workers however wore coveralls. Helmets were put on and off. Coveralls were worn by 10% of all the construction workers observed. Some the workers wearing coveralls would wear the coveralls up to the waist level with vests on the upper-body or no upper-body clothing. Un-Acclimatized workers wearing PPE were considered to be at a high risk of heat stress.

4.3 Assessment of Occupational Factors Affecting Construction Workers During Slab Construction

Occupational factors included exposure to direct sunlight, perceived physical exertion and workload intensity. To investigate the length of exposure of construction workers to direct sunlight based on their activities on site during slab construction. The study used continuous monitoring and observation approach to identify the levels of exposure to direct sun radiation. To carry out the investigation, the researcher and assistants undertook a passive role by observing the activities of the construction workers at construction sites. The aim was to record the length of time spent in the open field under direct exposure to the sun while working, record the perceived exertion using the Borg CR10 perceived exertion scale and classify workload based on the ACGIH screening criteria. Table 4.10 illustrates the Borg CR10 developed by Gunnar Borg in 1982 which uses several cues such as breathing pattern, sweat and fatigue level to determine the level of perceived exertion. Table 4.11 shows ACGIH guidelines which provides simple qualitative framework to classify workloads as light, moderate, heavy or very heavy. Table 4.8 shows the results of the observation of construction workers in the study. Finally the study was able to identify construction workers job group at risk of exposure to heat stress using a bar chart.

Table 4.8: Description of Activities observed: exposure levels, perceived exertion and ACGIH workload classification

No.	Occupational Activities Observed	Tasks/Activities observed	Exposure duration	Perceived physical exertion (Borg CR10 scale)	Classification of workload (ACGIH category)
1	Steel reinforcement works	Physical modification of steel reinforcement bars	Extremely High (4)	Very hard (7)	**Moderate (2)**
2	Walling	Laying blocks & mixing mortar	Extremely High (4)	Hard (5)	**Light (1)**
3	Formwork construction	Constant cutting and nailing	High (3)	Hard (6)	**Moderate (2)**
4	Concreting works	Carrying materials using buckets/wheelbarrows at rapid pace	Extremely High (4)	Very, very hard (8)	**Heavy (3)**
5	Plumbing & Electrical works	Physical modification of pipes & tying	Moderate (2)	Moderate (3)	**Light (1)**
6	Roofing works (pitched roof)	Constant cutting and nailing	Extremely High (4)	Hard (5)	**Moderate (2)**

Source: Field Study, 2022

Table 4.9 Direct Sun Exposure Duration Rating

Direct Sun Exposure Duration Rating		
Duration	Description	Rating
2 hrs and above	Extremely High	4
1.5-2 hrs	High	3
1-1.5 hrs	Moderate	2
1hr or less	Low	1

Source: Author, 2021

Table 4.10 Borg CR10 Scale

Borg CR10 scale	
Rating	Description
0	Rest
1	Very Easy
2	Easy
3	Moderate
4	Somewhat hard
5	Hard
6	Hard
7	Very Hard
8	Very, very hard
9	Nearly Maximal
10	Maximal

Source: Scaling Experiences during Work: Perceived Exertion and Difficulty' (Borg, 2004)

Table 4.11: ACGIH Screening Criteria

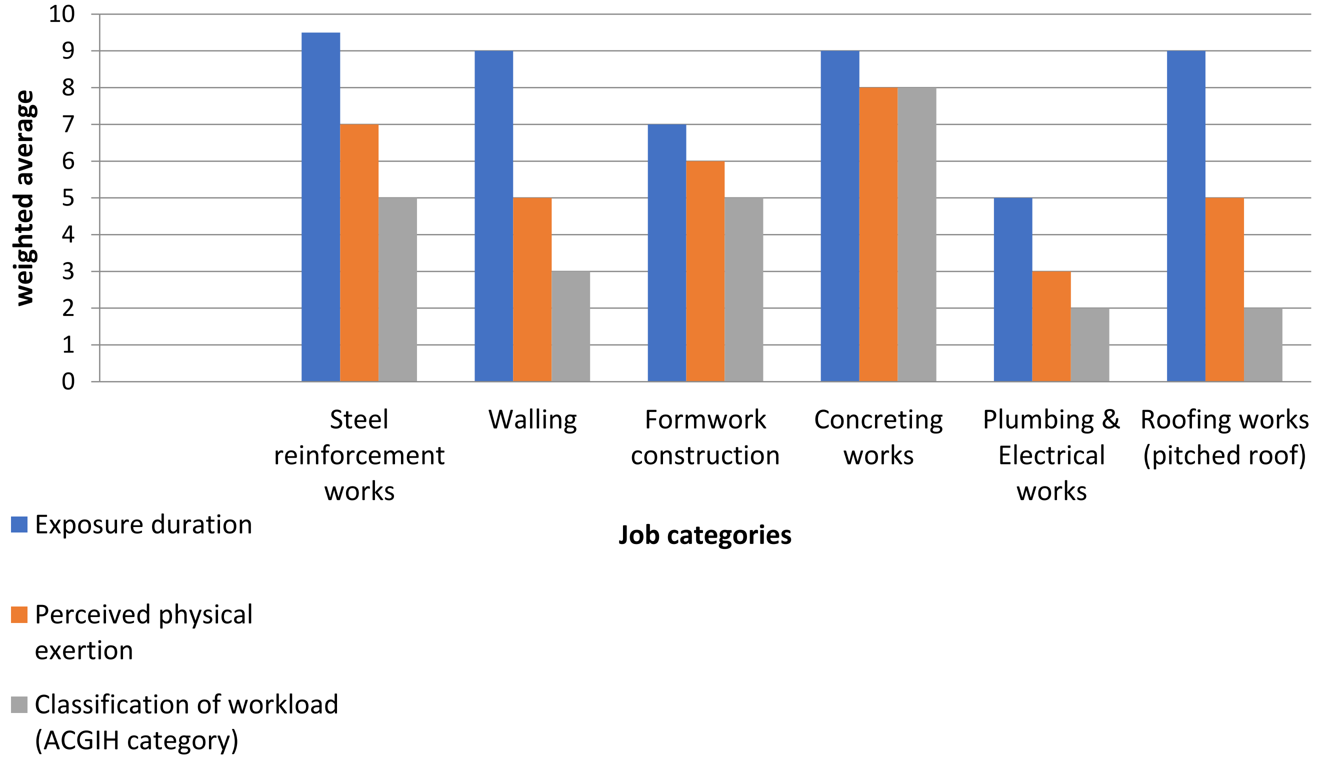
ACGIH screening criteria	
Description	Rating
Light	1
Moderate	2
Heavy	3
Very Heavy	4

Source: Adapted from (ACGIH, 2017)

4.4 Discussion on Occupational Factors Affecting Construction Workers that are Related to Heat Stress

The results of the observation in table 4.8 indicated that concreting workers were involved in more physically demanding construction activities followed by steel reinforcement works and formwork construction. Concreting works recorded a ‘Heavy’ classification according to the ACGIH workload classification while steel reinforcement works and formwork construction recorded ‘Moderate’ workloads. There were no ‘Extremely High’ workloads observed as per ACGIH classifications. Steel reinforcement works, walling and concreting works also recorded high ‘Extremely high’ exposure to the sun.

Figure 4.6: Activities observed: exposure levels, perceived exertion and ACGIH workload classification



Source: Field study, 2022

Figure 4.6 indicates the high level of physical exertion, exposure to direct sun in the open and workload intensity experienced by concreting construction workers therefore indicating a likelihood of heat stress affecting these workers based on occupational factors only. Majority of the construction workers were unskilled workers (67%) were prone to heat stress based on their occupational requirements which involved strenuous activities and working in the open sun. Further assessment of occupational activities indicates that construction workers aged between 18-30 years (44%) were likely to be unskilled formed the high risk group. Un-Acclimatized workers undertaking concreting works were the most extremely prone to heat stress. This accounted to 2% of all the workers. The matter was further aggravated if the construction workers were wearing PPE’s. However majority of the workers did not wear PPE’s. This indicates that, while the workers were protecting themselves from heat stress by avoiding PPE’s, they were exposing themselves to injury or even fatalities in the case of an accident. Figure 4.7 and 4.8 show some of the workers wearing PPE’s in Mombasa. These workers are at a higher risk of heat stress.

Figure 4.7: Walling works

Source: Field study, 2022

Figure 4.8: Formwork construction works

Source: Field study, 2022

4.5 Heat Levels Environmental Measurements: wet-Bulb, Dry-Bulb and Globe Temperature (WBGT) and Humidity in Mombasa

Field surveys were carried out at 42 construction sites around Mombasa where 463 construction workers assessed. Heat level measurements were Dry Bulb temperature, Wet Bulb Temperature, Globe thermometer temperature which was calculated to achieve the Wet Bulb Globe Thermometer (WBGT) measurements. Other recordings were the Relative Humidity and estimated air velocity using NIOSH guidelines. The measurements were taken using the following:

1. Dry Bulb temperature - Measurements were taken using a Wet and Dry bulb thermometer whose model is SK-RHG skSATO
2. Wet bulb temperature - Measurements were taken using a Wet and Dry bulb thermometer whose model is SK-RHG skSATO
3. Globe thermometer temperature. - Measurements were taken using a Globe thermometer whose diameter is 150mm.
4. Humidity – Humidity measurements were taken using KANOMAX Hygro-thermometer model 6805.

Figure 4.9: Wet and Dry bulb Thermometer and Globe thermometer in Mombasa

Source: Author at Field study, 2022

Measurements were taken after every 2 hours starting at 8am when most of the construction work began. Measurements were taken using a wet and dry bulb thermometer and the Globe thermometer which were placed on the ongoing construction as shown in figure 4.9. Table 4.6 shows the WBGT recorded values across 42 construction sites.

4.6 Wet-Bulb, Globe and Dry-Bulb Temperature (WBGT) records in Mombasa

Table 4.12 Wet-Bulb, Globe and Dry-Bulb Temperature (WBGT) results in Mombasa

	WBGT outdoor= 0.7 × Tnwb + 0.2 × Tg + 0.1 × Tdb (°C)				
Construction site	**8– 10am**	**10– 12pm**	**12– 2pm**	**2– 4pm**	**4 – 6pm**
1	27.7	29.9	32.3	31.1	28.5
2	26.3	30.5	35.6	32	27.7
3	30.4	33.6	36.2	33	29.9
4	26.8	32.5	33.7	31.5	28.8
5	26.5	29.7	32.4	30.6	28.4
6	26.2	29.9	31.8	30.7	27.2
7	30.5	33.8	38.4	33.9	31.5
8	26.2	29.6	33.8	31.6	28.4
9	27.9	30	33.3	32.1	28.6
10	26.5	30.5	32.7	31.3	27.5
11	29.9	31.2	34.1	32	31.1
12	27.6	32.8	34.2	32.6	28.1
13	27.4	32.3	33.9	31.5	27.2
14	26.2	31	33.6	31.7	27.6
15	28.5	33.7	35	33.5	31.2
16	30.5	35.8	37.2	34.2	31.2
17	30.3	34.4	36	34.1	31.5
18	29	32.6	33.7	31.9	29.6
19	28.2	32.3	34.4	32.6	30
20	28.5	32.1	34.6	32.7	29.8
21	26.8	31.7	33	31.5	29.2
22	29.3	32.8	35.2	33.7	29.9
23	29.8	33.8	35.5	34	31.5
24	30	34.1	36.6	34.1	31.1
25	29.1	32.2	34.3	32.9	30.8
26	26.5	30.3	31.9	30.9	28.4
27	29.5	32.1	32.5	31.7	27.5
28	27.4	30.8	32.4	31.6	27.5
29	26.8	30.2	32.1	30.7	27.5
30	30.1	33.3	35.2	33.4	31.3
31	26.8	29.6	31.3	30.8	27.5
32	30.3	33.9	36.5	34	31.1
33	27.6	31.4	33.5	31.8	29.3
34	26.5	30.3	32.9	30.7	28.4
35	28.4	33	34.7	32.5	30.4
36	28.3	33.1	35.5	32.6	30.6
37	27.6	32.8	34.9	32	30.7
38	27.4	31	33.3	31	28.4
39	26.5	29.6	33.9	31.4	29.1
40	28.2	32.7	34.6	32.5	30.8
41	27	31	32.8	30.7	27.9
42	29.4	33.5	35.7	33.5	28.8
Mean	**28.1**	**31.9**	**34.2**	**32.2**	**29.3**

Source: Field study, 2022

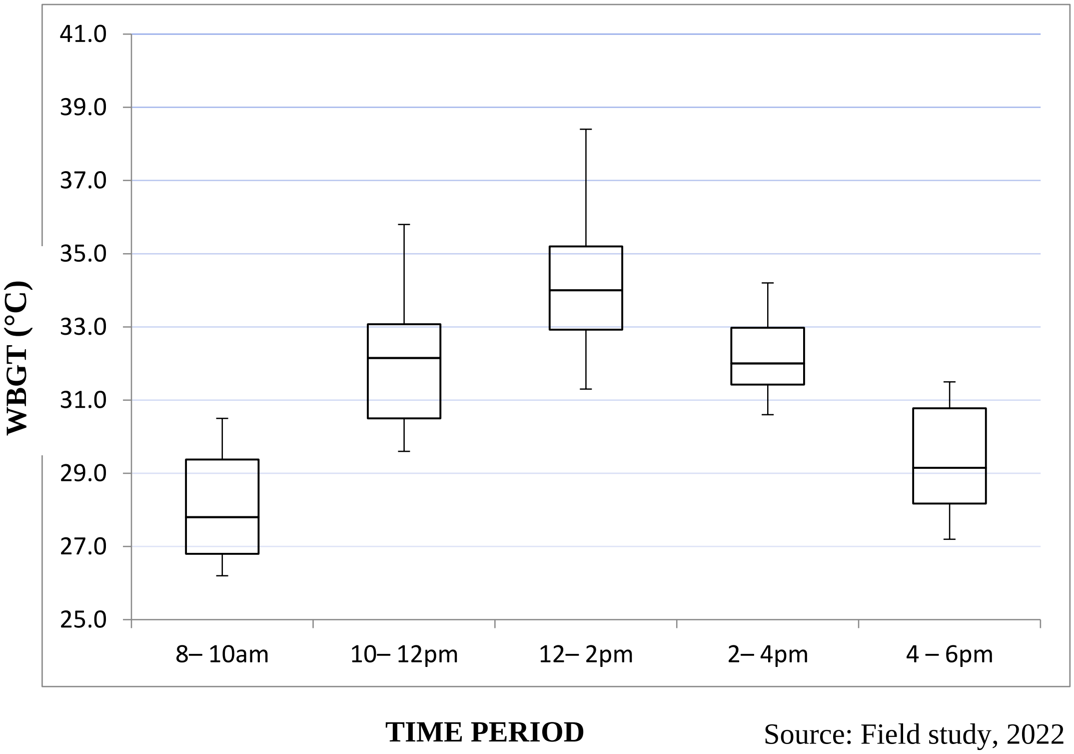
Table 4.13: Wet-Bulb, Globe and Dry-Bulb Temperature (WBGT) Mean, range, median & percentiles

Wet Bulb Globe Temperature (WBGT) Mean, range, median and percentiles in Mombasa

WBGT Index(°C)	**8-10am**	**10-12am**	**12-2pm**	**2-4pm**	**4-6pm**
Range	26.2 - 30.5	29.6 - 35.8	31.3 - 38.4	30.7 - 34.2	27.2 - 31.5
Mean	28.1	31.9	34.2	32.2	29.4
Median (2nd Quartile)	27.8	32.2	34.0	32.0	29.2
Minimum value	26.2	29.6	31.3	30.7	27.2
Maximum value	30.5	35.8	38.4	34.2	31.5
Q1 (1st Quartile)	26.8	30.5	32.9	31.4	28.2
Q3 (3ed Quartile)	29.4	33.1	35.2	33.0	30.8

Source: Field study, 2022

Figure 4.10: Highest & Lowest WBGT range recorded in relation to time of day



Source: Field study, 2022

Table 4.12 shows the range of the mean values recorded between 8 am to 6pm with measurement taken every two hours using a Wet Bulb Globe Thermometer. Table 4.13 indicates the median, 1st Quartile, 2nd Quartile and 3rd Quartile generated from Table 4.12 that was used to generate a box and whisker plot to assist the study in understanding the recorded results. The box and whisker plot was used to analyze the inter-percentiles records.

4.6.1 Discussion on the WBGT Results

The WBGT serves as an indicator of the thermal stress standards of the International Organization for Standardization ISO 7243 and is used to determine the ergonomic impact of the thermal environment. Figure 4.10 shows a box plot indicating the maximum and minimum WBGT values recorded between 8am and 6pm in 42 construction sites in Mombasa. WBGT was measured every 2 hours from 8am to 6pm. Although the majority of results at 12-2pm were between 32.9 – 35.2, the maximum recorded WBGT (38°C) at 12-2pm, was considered to be at 'Very high risk' and dangerous according to ACGIH standards. This was unexpected even during the hottest months in Mombasa. At least 75% of the results at 12-2pm recorded WBGT results above 32.9°C. With 75% of the results above 32.9°C, it indicates that surrounding conditions on a construction site can result in very high WBGT values and predicting WBGT from meteorological data is not reliable. The peak WBGT was recorded between 12pm midday and 2pm. Lower levels of WBGT were observed at 8-10am and 4 -6pm.

There were some similarities in WBGT records at 10-12pm and 2-4pm with medians of 32.2°C and 32.0°C respectively. This may imply that workers are likely to face the same heat stress environmental conditions during these 2 periods. The difference being that majority of the results at 10-12pm were 32.2°C and below while at 2-4pm majority of the results were above 32.0°C. The lowest results recorded (26.2°C & 27.2°C) at 8-10am and 4-6pm were generally safe environments for construction workers.

4.7 Humidex Records in Mombasa

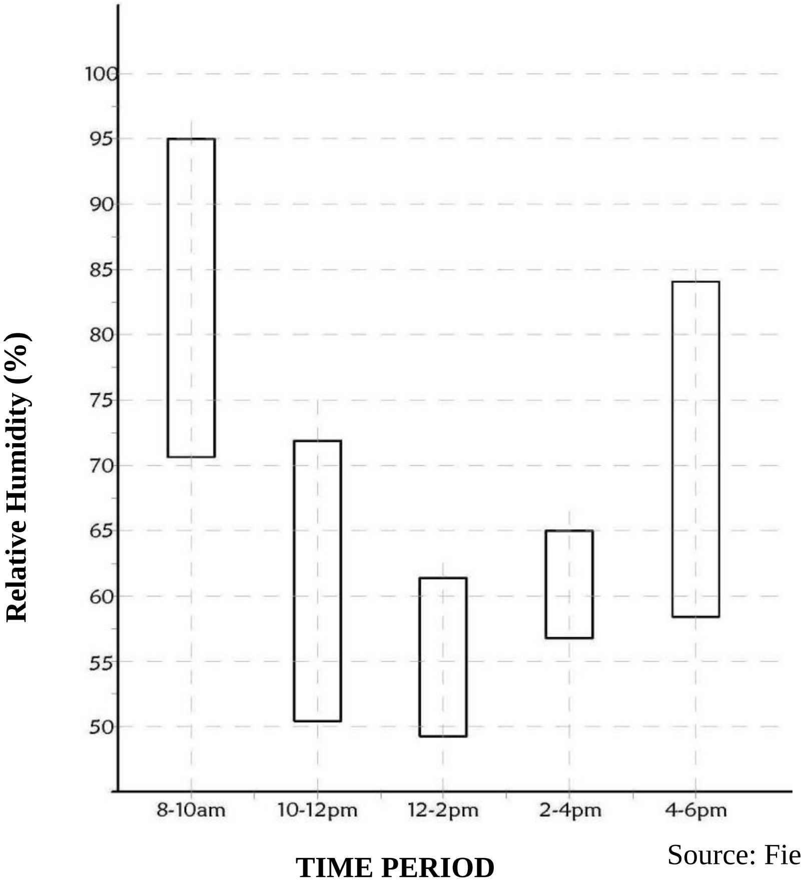
Table 4.14: Humidity results in Mombasa

Construction site	8– 10am	10– 12pm	12– 2pm	2– 4pm	4 – 6pm
1	88	58	50	59	74
2	85	60	55	61	79
3	92	63	56	62	82
4	94	62	51	57	76
5	90	59	57	62	81
6	83	58	50	58	79
7	85	60	49	57	79
8	93	65	63	56	78
9	95	60	51	57	83
10	92	58	54	60	80
11	89	64	53	58	80
12	83	52	48	56	82
13	91	57	49	58	79
14	79	53	48	56	57
15	89	58	52	58	77
16	85	61	54	60	79
17	95	60	51	62	81
18	92	65	55	60	82
19	88	56	50	56	76
20	85	55	48	56	67
21	94	59	49	57	82
22	95	63	50	58	69
23	90	60	53	57	79
24	80	54	48	56	78
25	89	57	50	58	74
26	90	55	50	59	78
27	86	53	48	60	80
28	91	60	48	56	84
29	95	58	50	59	70
30	87	54	48	56	78
31	84	52	48	57	69
32	95	56	49	56	72
33	90	55	49	59	75
34	94	56	50	59	68
35	95	59	50	58	74
36	87	63	55	61	79
37	82	54	48	60	83
38	86	60	51	59	77
39	91	64	54	62	80
40	93	63	54	61	79
41	88	59	51	60	84
42	89	61	52	59	78
Mean	**89.1**	**58.5**	**51.2**	**58.5**	**77.2**

Source: Field study, 2022

4.7.1 Discussion on the Humidity Results

Figure 4.11: Highest & Lowest Humidity levels recorded in relation to time of day

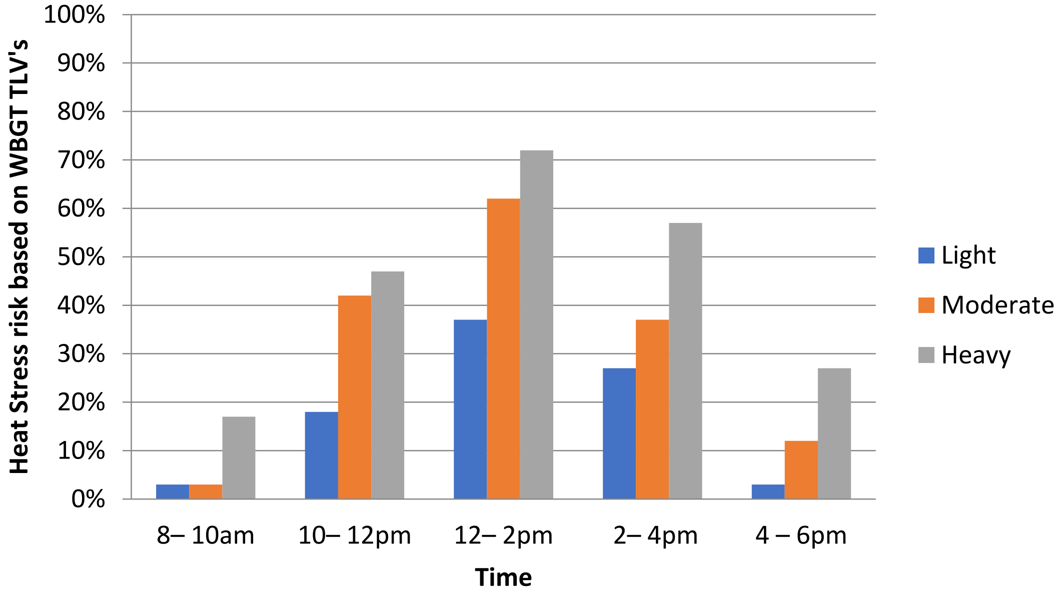


Source: Field study, 2022

Table 4.14 shows humidity levels recorded every two hours at 42 construction sites. The aim was to understand the characteristic of humidity levels during the day. High Relative Humidity in the morning was attributed to the low Air temperature in the morning between 8-10am as shown in Figure 4.11 above. Low temperatures decrease the ability of air to hold water. Relative humidity levels above 60% were recorded in Mombasa at 12-2pm when the highest WBGT levels were recorded. At such levels, the body's ability to cool itself may be compromised and hence negative impacts such as heat exhaustion may occur. Humidity is not factored in the measurement of WBGT. Therefore this study recorded Humidity measurements separately so as to calculate the prevailing Humidex Index in Mombasa. Figure 4.12 and 4.13 show the levels of risk in percentage in relation to light, moderate and heavy work between 8am and 6pm.

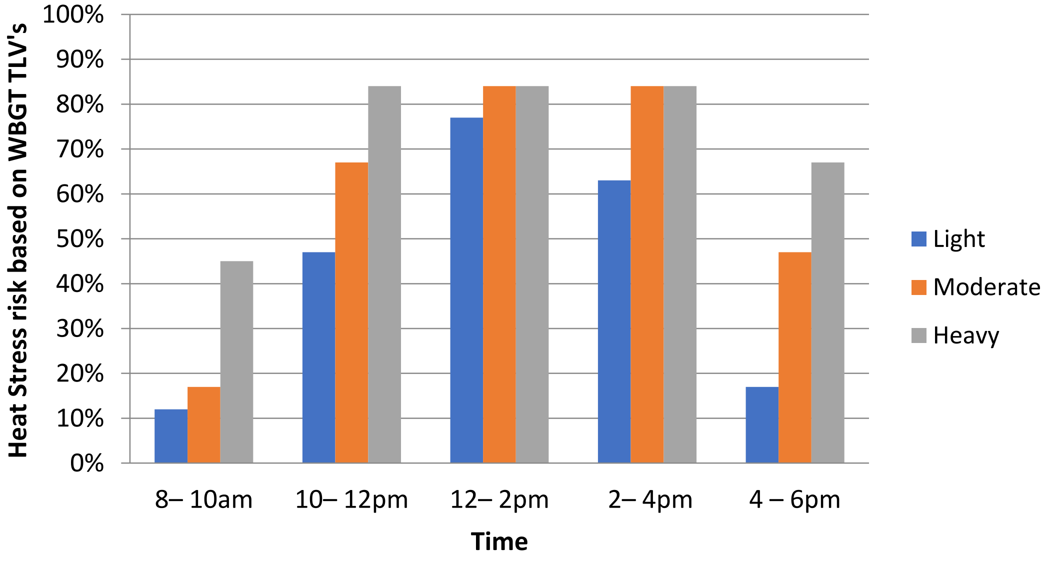
4.8 Assessment of Heat Stress Risk on Construction Workers Using the WBGT Index and Humidex Index

Figure 4.12: Heat stress risk for light, Moderate and Heavy classified work on a construction site in Mombasa for Acclimatized workers



Source: Field study, 2022

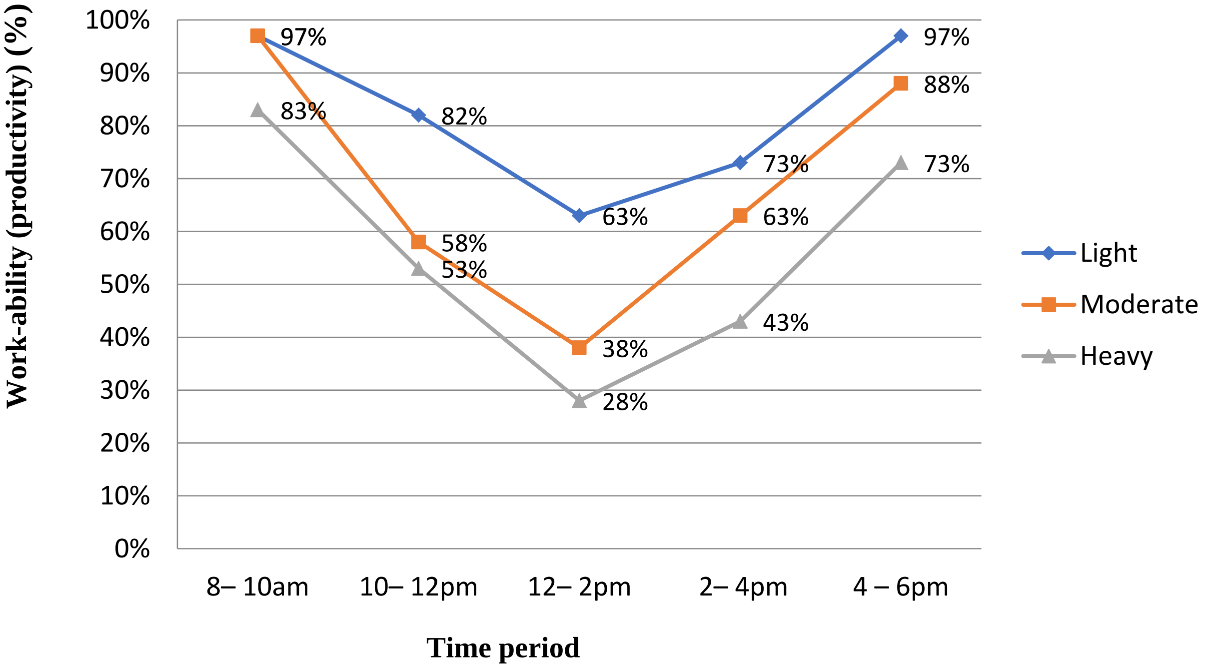
Figure 4:13 Heat stress risk for light, Moderate and Heavy classified work on a construction site in Mombasa for Un-Acclimatized workers



Source: Field study, 2022

WBGT values were compared with ACGIH Thermal Limit Values (TLV’s) workload Intensity (see figure 2.7) for Light work (walling and plumbing, electrical works), Moderate work (Steel reinforcement Formwork construction works and roofing works) and Heavy work (concreting works). Thermal limits were exceeded in all the categories. Taking into consideration Lunch breaks, acclimatized workers undertaking heavy work exceeded recommended TLV by 17-72% and Un-acclimatized workers by 44-84%. Construction workers exposure above the TLV’s recommended by ACGIH can result in increased core body temperature (>37°C). ACGIH recommends Administrative control to reduce the heat stress exposure to a safe level to reduce the risks. This is done through the construction manager recommending hourly work break regimens. None of the construction sites were willing to stop work for some minutes as this would slow down the construction. Construction workers were willing to spend the day in the open sun even if they were not being productive because it was expected of them to work through the 8 hours by their employers. Figure 4.14 indicates construction workers workability (productivity) levels based on WBGT TLV’s in Mombasa during the day without any modifications to the site. Workability of construction workers is reduced to up to 72% (100-28%) during 12-2pm period. A well-managed site can introduce modifications such as introduction of a resting shade to allow workers to rest for some rest before proceeding with work.

Figure 4.14: Workability (productivity) levels of construction workers



Source: Field study, 2022

4.9 Discussion on the Humidex Index Results

Table 4.15: Highest & Lowest recorded Humidex values and the degree of discomfort

	Time	**Average Humidex Value**	**Degree of Comfort**
1	8 – 10am	37	Some Discomfort
		40	Great Discomfort, avoid exertion
2	10 – 12am	40	Great Discomfort, avoid exertion
		43	Great Discomfort, avoid exertion
3	12 – 2pm	47	Dangerous
		50	Dangerous
4	2 – 4pm	43	Great Discomfort, avoid exertion
		44	Great Discomfort, avoid exertion
5	4 – 6pm	38	Some Discomfort
		44	Great Discomfort, avoid exertion

Source: Field study, 2022

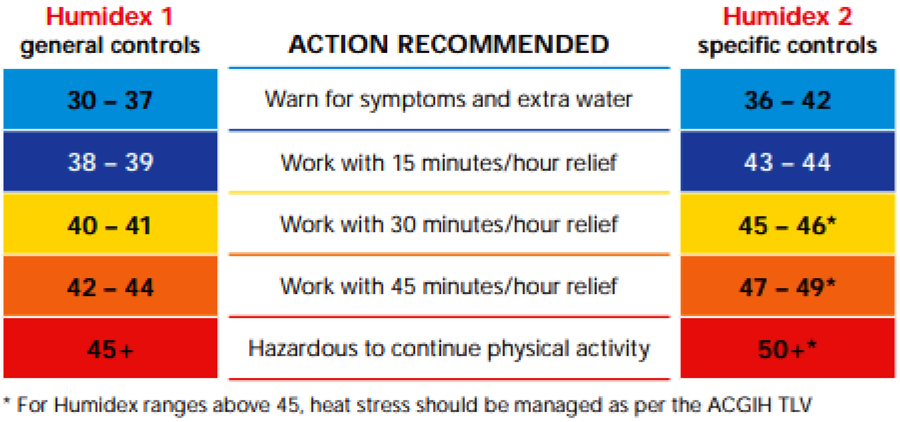
Humidex Index Guidelines

Humidex Value	***Degree of Comfort***
36	No discomfort
37	Some Discomfort
40	Great Discomfort, avoid exertion
47	Dangerous
50	Heat-stroke imminent

In the analysis of values using the Humidex Index, Mombasa recorded ‘Dangerous’ levels of Heat Stress (see table 4.15). These workers were also suffering from ‘Great Discomfort’ during the entire part of the day from 10am until the end of the workday. Workers were likely to suffer heat fatigue or heat exhaustion. Humidex Index chart advised workers to avoid exertion at such levels of discomfort. It was noted that higher levels of Humidity in Mombasa was the major factor in the rate of discomfort observed. When humidity is high, we feel warmer because our perspiration evaporates more slowly.

The Humidex Index gives advices on heat stress response to acclimatized workers who are working under moderate physical work in Humidex 2 and heavy physical work in humidex 1 in figure 4.15.

Figure 4.15: Humidex Index Heat Stress Response



Humidex 1 general controls	ACTION RECOMMENDED	Humidex 2 specific controls
30 – 37	Warn for symptoms and extra water	36 – 42
38 – 39	Work with 15 minutes/hour relief	43 – 44
40 – 41	Work with 30 minutes/hour relief	45 – 46*
42 – 44	Work with 45 minutes/hour relief	47 – 49*
45+	Hazardous to continue physical activity	50+*

* For Humidex ranges above 45, heat stress should be managed as per the ACGIH TLV

Source: OHSCO Canada, (2009)

Humidex response measures are linked to ACGIH TLV’s. Construction workers working under ‘dangerous’ conditions (47-50 humidex values) and under moderate and heavy physical work are required to observe work rest regimens as described in figure 4.15. The ‘dangerous’ levels were experienced between 12-2pm which was partly a rest break period for lunch observed at 1-2pm.

4.10 Assessment of Heat Stress Risk using a Weighted Average of Occupational Factors and Environmental factors

Table 4.16: Weighted Average of Occupational and Environmental factors that affect construction workers heat stress levels

		Occupational factors			**Environmental factors** (WBGT-Temperature, solar radiation & wind chill) + Humidex-humidity)							
					Time of the day							
No.	**Occupational Activities Observed**	**Exposure duration**	**Physical exertion**	**Workload**	**8-10am**	**10-12pm**	**12-2pm**	**2-4pm**	**4-6pm**	**Mean**		**Heat stress exposure levels**
1	Steel reinforcement works	4	4	2	1	2	4	3	1	2.625	**3**	High
2	Walling	4	3	1	1	1	2	2	1	1.875	**2**	Moderate
3	Formwork construction	3	3	2	1	2	4	3	1	2.375	**2**	Moderate
4	Concreting works	4	4	3	1	3	4	3	2	3.000	**3**	High
5	Plumbing & Electrical works	2	2	1	1	1	2	2	1	1.500	**2**	Moderate
6	Roofing works (pitched roof)	4	3	2	1	2	4	3	1	2.500	**3**	High
	Mean	3.500	3.167	1.833	1.000	1.833	3.333	2.667	1.167			
		4	**3**	**2**	**1**	**2**	**3**	**3**	**1**			
	Heat stress exposure levels	Very high	High	Moderate	Low	Moderate	High	High	Low			

Source: Field study, 2022

Heat stress exposure levels

4 – Very high risk 3 – High risk 2 – Moderate risk 1– Low risk

The study used a Weighted Average of the independent variables to find out the level of significance in relation to the dependent variables as shown in Table 4.16. The duration of exposure to the open sun was found to be the most significant variable with a mean score of 3.500. The study found that exposure duration to the open sun was a major factor for heat stress among construction workers. Workers exposed to the sun between 12pm -4pm and undertaking moderate or heavy work were considered to be at ‘high risk’ of heat stress. Workers undertaking Concreting works such as slab construction and column casting (mean 3.00) were considered to be at ‘high risk’ of heat stress followed by steel reinforcement workers (mean 2.625) and roofing workers (mean 2.500).

The study found out that physical exertion (mean 3.167) is also an important variable since body heat is a direct function of physical activity. The construction sites visited did not have official water breaks and a shade specifically made to for relieving construction workers in the open sun. Some sites which had natural shades such as a tree as shown on figure 4.16 which greatly benefited the workers.

Figure 4.16: Construction workers resting under a tree during a lunch break

Source: Field study, 2022

4.11 Hypothesis Testing

The purpose of the study was to assess the heat stress levels of construction workers in hot and humid environments. A hypothesis test was carried out with a statistical test using WBGT and Humidex Index environmental samples collected in Mombasa County. A one way Between-Subject ANOVA test was used for the analysis. One-way ANOVA compares the means of two or more independent groups to determine if there is statistical evidence that the associated population means are significantly different. The study had five independent samples of WBGT and Humidex samples recorded between 8am and 6pm as shown in Table 4.17 and 4.19. The study hypothesis below was investigated.

H_0: Construction workers are not significantly affected by the levels of heat stress in Mombasa during daytime work due to the warm and humid environmental conditions.

H_1: Construction workers are significantly affected by the levels of heat stress in Mombasa during daytime work due to the warm and humid environmental conditions.

Table 4.17: WBGT means and Standard Deviations

Wet Bulb Globe Temperature (WBGT) Statistics in Mombasa

WBGT Index	**8-10am**	**10-12am**	**12-2pm**	**2-4pm**	**4-6pm**
Mean	28.1	31.9	34.2	32.2	29.3
Standard dev.	1.44	1.59	1.59	1.13	1.45
Standard Error (SE)Mean	0.22	0.25	0.25	0.17	0.22
Variance	2.07	2.53	2.53	1.27	2.10

Source: Field study, 2022

Figure 4.17: WBGT ANOVA output

ANOVA

Source of Variation	*SS*	*df*	*MS*	*F stat.*	*P-value*	*F crit.*
Between Groups	986.15	4	246.54	117.41	0.00	2.42
Within Groups	430.47	205	2.10			
Total	1416.62	209				

Source: Field study, 2022

F-Test

F-test is to evaluate whether the expected values of quantitative variables differ from each other within multiple groups. Figure 4.17 above shows the ANOVA output for the WBGT samples (*df*=4, F=117 p=0.00) which indicates that there are significant differences in means based on the time of the day the samples were taken. Because the values of *F stat.*>*F crit,* the samples collected in Mombasa are considered statistically significant.

P-value

The ***P***-value for the test was ***P***= 0.000. The smaller the *P*-value signifies that the null hypothesis should be rejected. A *P*-value of ***P***=0.000 was less than Level of Significance ($\boldsymbol{\alpha}$ = 0.05) and therefore was statistically significant. The Confidence Interval used was **95%** was used for the Hypothesis. Therefore, the null hypothesis of Construction workers in Mombasa are not at a significantly high risk of heat stress due to the hot and humid environmental conditions was rejected.

Post hoc test

The post hoc test used the Bonferroni Adjustment which is a multiple comparison test used in statistical analysis. A true or False result indicate whether or not there is a significance between two samples compared. Using a two T-test and a Bonferroni Adjustment of 0.005, the following significance was observed in Table 4.18.

Table 4.18: Bonferroni Adjustment output

	Comparison sample (time)	**P(T<=t) two-tail**	**Statistical difference** (TRUE/FALSE)
1	8-10am & 10-12pm	6.17E-19	TRUE
2	8-10am & 12-2pm	9.7E-31	TRUE
3	8-10am & 2-4pm	2.06E-24	TRUE
4	8-10am & 4-6pm	0.000223	TRUE
5	10-12pm & 12-2pm	7.89E-09	TRUE
6	10-12pm & 2-4pm	0.378096	FALSE
7	10-12pm & 4-6pm	1.2E-11	TRUE
8	12-2pm & 2-4pm	4.97E-09	TRUE
9	12-2pm & 4-6pm	1.53E-24	TRUE
10	2-4pm & 4-6pm	3.23E-16	TRUE

Source: Field study, 2022

The results in Table 4.18 above indicate that there are differences between WBGT results across the samples except at 10-12pm and 2-4pm. This indicates that the significance between the samples is acceptable. The effects of heat stress felt at 10-12pm and 2-4pm therefore indicate some similarities while the effects felt between 8-10am, 12-2pm and 4-6pm are significantly different. The study found out that working between 12-2pm put construction workers at high risk of heat stress followed by 2-4pm.

Table 4.19: Humidex means and Standard Deviations

Humidex Statistics in Mombasa

Humidex Index	**8-10am**	**10-12am**	**12-2pm**	**2-4pm**	**4-6pm**
Mean	89.1	58.5	51.2	58.5	77.96
Standard dev.	4.38	3.61	3.15	1.94	5.39
Standard Error (SE)Mean	0.68	0.56	0.49	0.30	0.83
Variance	19.15	13.03	9.95	3.77	30.54

Source: Field study, 2022

Figure 4.18: Humidex ANOVA output

ANOVA

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	40020.31	4	10005.08	719.34	0.00	2.42
Within Groups	2614.82	188	13.91			
Total	42635.13	192				

Source: Field study, 2022

F-Test

Figure 4.18 above shows the ANOVA output of Table 4.19 of the Humidex samples. The output (*df*=4, F=719 p=0.00) indicates that there are significant differences in means based on the time of the day the samples were taken. Because the values of *F stat.>F crit,* the samples collected in Mombasa are considered statistically significant.

P-value

The ***P***-value for the test was ***P***= 0.000. The smaller the *P*-value signifies that the null hypothesis should be rejected. A *P*-value of ***P***=0.000 was less than Level of Significance (α = 0.05) and therefore was statistically significant. The Confidence Interval used was **95%** was used for the Hypothesis. Therefore, the null hypothesis of Construction workers in Mombasa are not at a significantly high risk of heat stress due to the hot and humid environmental conditions was rejected.

4.12 Challenges encountered during the Field study and how they were mitigated

Although the author carefully prepared this study to meet its research objectives, there are still some shortcomings identified during the study. Some of the challenges I encountered are:

1. Access to construction sites took a lot of convincing by the researcher as contractors wanted to clearly understand why the research was being done and where it will be taken.

2. The instruments used to research were delicate and could not be transported using public means and therefore the researcher used his own personal transport with instruments carefully and safely secured
3. Due to the Covid-19 lockdown, the time taken to undertake the research was extended due to closure of some construction sites.
4. Instruments used for measuring required training the research assistant on site before commencement of the field study.

4.13 Conclusion

To record the duration of exposure to direct sunlight, perceived physical exertion and workload intensity of construction workers on site during construction. The study found that concreting works were the most affected by sun exposure, high workload intensity and physical exertion followed by steel reinforcement bar workers.

To measure the heat levels of a construction site in a hot and humid environment. WBGT was measured every 2 hours from 8am to 6pm at 41 construction sites in Mombasa. The highest recorded WBGT of 38°C recorded between 12-2pm was considered to be at ‘Very high risk’ and dangerous according to ACGIH standards. Humidity values were at highest level between 8-10am and 4-6pm.

The study assessed heat stress risk on construction workers using the WBGT index and Humidex index. Construction workers in Mombasa were found to be working at levels of ‘Great Discomfort’ according to the WBGT TLV’s. Taking into consideration Lunch breaks, acclimatized workers undertaking heavy work exceeded recommended TLV by 17-72% and Un-acclimatized workers by 44-84%. Using the Humidex Index, workers in Mombasa were found to be working at ‘Dangerous’ between 12-2pm and ‘Great Discomfort’ from 10am in the morning.

CHAPTER FIVE:

SUMMARY STUDY FINDINGS CONCLUSIONS AND RECOMMENDATIONS

5.1 Introduction

This study set-out to assess the heat stress exposure levels on construction workers in the warm and humid environment of Mombasa. This chapter presents a summary of the key findings of the study. It also provides conclusions that were drawn from the research, as well as recommendations and offers suggestions for future research on construction workers exposure to heat stress at construction sites in warm and humid environments. Areas of further research are also provided in outline. Additionally, the study sought to test the hypothesis, in the alternate that, Construction workers are significantly affected by the levels of heat stress in Mombasa during daytime work due to the warm and humid environmental conditions.

5.2 Summary of Study Findings

The study had 3 objectives which were: to assess occupational factors affecting construction workers that are related to heat stress on site during construction; to measure the heat levels of construction sites in a warm and humid environment; to assess heat stress risk levels on construction workers using the WBGT Index and Humidex Index.

Objective one: To Assess Occupational Factors Affecting Construction Workers that are Related to Heat Stress on Site during Construction.

To carry out the investigation, the researcher together with trained research assistants undertook the role by continuously observing the activities of the Construction workers on the construction site. The aim was to record the amount of time spent in the open field under direct exposure to the sun while working, secondly to record the perceived exertion using the Borg CR10 perceived exertion scale and thirdly to classify workload based on the ACGIH screening criteria. The study was carried out between 8am and 6pm. 463 sampled construction workers were classified under

6 sub-categories. The sub-categories were Steel Reinforcement works, Walling, Form work construction, Concreting, Plumbing and electrical works and Roofing works. Results of the observation indicated that concreting workers were involved in more physically demanding construction activities followed by steel reinforcement works and formwork construction. Only Concreting works recorded a ‘Heavy’ classification according to the ACGIH workload classification while steel reinforcement works and formwork construction recorded ‘Moderate’ workloads. Further assessment of occupational activities indicates that construction workers aged between 18-30 years (44%) were likely to be unskilled formed the high risk group. Un-Acclimatized workers undertaking concreting works were the most prone to heat stress but accounted for only 2% of the workers. The study findings was successful because by classifying the construction workers in into light, moderate and heavy work, the study was able to identify activities that lead to heat stress through observation.

Objective two: To measure the Heat Levels of Construction Sites in a Warm and Humid Environment.

Field surveys were carried out 42 construction sites in Mombasa County in the months of January and February in the year 2022. Measurements were taken using Wet and Dry bulb thermometer whose model is SK-RHG skSATO (Japan) after every 2 hours starting at 8am in the morning to 6pm in the evening. Measurements were taken using a wet and dry bulb thermometer and the Globe thermometer whose values generated the WBGT. The highest WBGT results were recorded between10-12pm (35.8°C) and 12-2pm (38.4°C). These results are considered to be at ‘dangerous levels.’ This could have been due to the reflection and re-radiation experienced by the globe thermometer at some construction sites.. Humidity results were also recorded together with WBGT. Highest humidity values were recorded between 8-10am and 4-6pm however humidity recorded during other periods of the day were considered high. Relative humidity levels above 60% were recorded in Mombasa at 12-2pm when the highest WBGT levels were recorded. At such levels, the body’s ability to cool itself may be compromised and hence negative impacts such as heat exhaustion may occur. Relative Humidity is not factored in the measurement of WBGT. Therefore this study recorded Relative Humidity measurements separately so as to calculate the prevailing Humidex Index in Mombasa. The highest Relative Humidity values were recorded in the morning between 8am and 10am (95%) and in the evening between 4-6pm (84%) The objective was achieved successfully.

Objective three: To Assess the Heat Stress Risk on Construction Workers using the WBGT Index and Humidex Index.

WBGT values were compared with ACGIH Thermal Limit Values (TLV's) workload Intensity for Light work (walling and plumbing, electrical works), Moderate work(Steel reinforcement Formwork construction works and roofing works) and Heavy work(concreting works). Thermal limits were exceeded in all the categories. Taking into consideration Lunch breaks, acclimatized workers undertaking heavy work exceeded recommended TLV by 17-72% and Un-acclimatized workers by 44-84%. Workability (productivity) of construction workers undertaking 'heavy work' is reduced to up to 72% during 12-2pm period. Using the Humidex Index, the study found out that construction workers were under 'Great Discomfort' during the entire part of the day from 10am until the end of the workday with 12-2pm recording 'dangerous level.' Both WBGT and Humidex results indicated that the highest levels of heat stress was between 12pm-2pm followed by 10am-12pm and 2pm-4pm which had similar characteristics.

Construction managers can therefore schedule physically demanding work in the morning before the heat levels rise during midday. Construction managers need to keep track of the WBGT levels during construction and modify sites to to allow workers to rest and recover to increase productivity. The study therefore achieved its Objective, successfully.

5.3 Conclusion

The research sought to assess Heat stress on Construction workers in Mombasa County. The first sub Hypothesis H_0: Construction workers are not significantly affected by the levels of heat stress in Mombasa during daytime work due to the warm and humid environmental conditions was rejected and an alternate hypothesis H_1: Construction workers are significantly affected by the levels of heat stress in Mombasa during daytime work due to the warm and humid environmental conditions accepted. The study concluded that Construction workers in Mombasa face a likelihood of heat stress at between 12noon and 2pm where both the WBGT Index and Humidex Index results indicated ‘dangerous levels’. A construction worker wearing PPE working in the open sun under hot and humid ‘dangerous levels’ and has no opportunity to remove the PPE is at ‘very high risk of heat stress.

Temperatures on construction sites can reach higher levels than the reported meteorological data. Contractors are therefore recommended to measure the WBGT on construction sites in hot and humid environments. This can be achieved by the use of automatic instruments such as QUESTemp 44 which give readings without calculation and are therefore user-friendly. Contractors should then issue an alert to construction workers working in the open environment to protect them from the likelihood of heat stress. If this is not followed the likelihood of reduced productivity would persist. While workers seemed physically tired, none of them stopped working when they were required to work and hence the researcher’s assumption is that the construction workers were working at self-pace. Self-pace has been known to be a sustainable way of combating heat stress. Another assumption was that construction workers were willing to spend the day in the open sun even if they were not being productive because it was expected of them to work through the 8 hours by their employers. The study concluded that all construction workers were affected by heat stress but those undertaking moderate and heavy work were most affected by reduced work-ability at construction sites in Mombasa especially during midday.

5.4 Recommendations

i. It is recommended that modifications of all sites in Mombasa should be carried out to ensure risk of heat stress is reduced. These modifications include provision of a small shaded area with a water drinking point in all construction sites in Mombasa. The study recommends that this should be a mandatory obligation by the construction firm. The shade would allow a worker to recover when heat stress effects are experienced.

ii. The study also strongly recommended the development of heat exposure guidelines for hot and humid environments in Kenya. A WBGT and Humidex Index chart specifically for Mombasa and neighboring hot and humid environments should be created and adopted by an institution such as the NCA. These charts would indicate guidelines to follow when harmful WBGT and Humidex values are reached. Currently there are no guidelines for workers exposed in the open sun in OSHA Kenya. The Built Environment Departments in Kenyan universities can propose these guidelines to the NCA so that they can be adopted by OSHA Kenya through NCA.

iii. Worker rotation should be adopted in jobs that require high physical exertion, high workload intensity and high exposure to direct sunlight such as the concreting works such as slab construction. These workers have greater chances of suffering from heat stress and therefore working on rotational basis would immensely improve productivity, the health of the workers and reduction in accidents.

iv. NCA recommended PPE’s were not worn by majority of workers who were at risk of heat stress. There was likelihood that workers were uncomfortable carrying out physically demanding work in PPE’s. Dress code for workers in hot and humid environments should be studied in detail and revised for the health and safety of construction workers. More porous clothing should be adopted to replace the bulky clothes currently in place in these environments.

v. Work and rest schedules should be adopted by contractors to enable workers to recover from an intensive work so as to make them more productive. ACGIH guidelines should be further modified to fit Kenya’s working conditions whereby rest schedules are considered a waste of labour cost. The study noted that workability between 12noon and 4pm was greatly reduced especially for ‘moderate’ and ‘heavy’ work according to ACGIH classification. To enable productivity of the construction workers, work rest schedules should be adopted during this period (12-4pm) to enable construction workers to work at optimum levels. If this is not implemented construction workers are likely to work at slower rates during the period when heat stress levels are higher than other periods (morning and evening).

5.5 Suggestions for Further Research

i. A study undertaken for a longer period is likely to give a better assessment of heat stress on construction workers. Construction workers should be observed over a longer period of time because heat stress effects may appear later.
ii. A combination of both heat strain which takes into account the human body and heat stress which relates to the environment should be studied at the same time in the hot and humid environment of Mombasa. This however requires a team of two or more researchers because the work involves studying many more variables. New knowledge can be generated from additional variables.
iii. A larger population of the subjects can be further studied by conducting studies on various sites across the broader hot and humid environments in Kenya. This longitudinal study will produce a better understanding of the phenomenon than a cross-sectional study because it will have been conducted many times, over many years instead of being conducted at one point in time.

REFERENCES

accuweather.com. (n.d.). *accuweather*. Retrieved February 29, 2020, from accuweather.com: https://www.accuweather.com/en/ke/mombasa/223233/march-weather/223233?year=2020

ACGIH. (2017). *TLVs and BEIs: Threshold limit values for chemical substances and physical agents and biological exposure indices*. Cincinnati, OH: ACGIH Worldwide.

Acharya, P., Boggess, B., & Zhang, K. (2018). Assessing Heat Stress and Health among Construction Workers in a Changing Climate: A Review. *International Journal of Environmental Research and Public Health , 15* (247).

Aliaga, M., & Gunderson, B. (2002). *Interactive Statistics* (2nd ed.). Portland, OR: Book News, Inc.

Aliasghar, F. (2014). Heat Stress Level among Construction Workers. *Iranian J Publ Health* , 43 (4), 492 - 498.

Al-Bouwarthan, M., Quinn, M. M., Kriebel, D., & Wegman, D. H. (2019). Assessment of Heat Stress Exposure among Construction Workers in the Hot Desert Climate of Saudi Arabia. *Annals of work exposures and health, 63*(5), 505–520. https://doi.org/10.1093/annweh/wxz033

Arbury, S., Jacklitsch, B., Farquah, O., Hodgson, M., Lamson, G., Martin, H., et al. (2014). Heat Illness and Death Among Workers - United States. *MMWR. Morbidity and mortality weekly report , 6331,* 661-665.

Asefi-Najafabady, S., Vandecar, K. L., & Seimon, A. (2018). Climate change, population, and poverty: vulnerability and exposure to heat stress in countries bordering the Great Lakes of Africa. *Climate Change* , 148 (4), 561-573.

ANSI/ASHRAE standard 55 (2010). *Thermal environmental conditions for human occupancy*. (2010). Atlanta, Ga: ASHRAE.

Babbie, E. (2013). *The practice of social research* (13th ed.). Wadsworth: Cengage Learning.

Bell, P. A. (1981). Physiological comfort, performance and social effects of heat stress. J*ournal of Social Issues* , 71-84.

Bernard, T. (1999). Heat stress and protective clothing: an emerging approach from the United States. *The Annals of occupational hygiene, 43 5,* 321-7 .

Berg, B. L. (2001). *Qualitative Research Methods - for social sciences* (4th ed.). Harlow: Pearson.

Borg, G (2004). Scaling Experiences during Work: Perceived Exertion and Difficulty. In: N. Stanton et. al (Eds.) Handbook of Human Factors and Ergonomics Methods (pp. 11-1-11-7).

London and New York: CRC PressBorg, W., & Gall, M. (1989). *Education Research.* New York: Longman.

Canadian Centre for Occupational Health and safety. (2020) Retrieved June 15, 2020, from ccohs.ca : https://www.ccohs.ca/oshanswers/phys_agents/humidex.html

Chan, A. P., Yi, W., & Wong, D. P. (2012). Determining an optimal recovery time for construction rebar workers after working to exhaustion in a hot and humid environment. *Building and Environment* , 58, 163 - 171.

Chan, A., & Yi, W. (2012). Optimizing work - rest schedule for construction rebar workers in hot and humid environment. *Building and Environment* , 104-113.

Chan, A., Yi, W., Wong, D., Yam, M., & Chan, D. (2012). Developing a heat stress model for construction workers. J. Facil. Manag. , 59 -75.

Cheung, S. S., Lee, J.K., & Oksa, J. (2016). Thermal Stress, human performance, and physical employment standards. *Applied physiology, nutrition, and metabolism,* 41(6 Suppl 2), S148 - S164.

Doloi, H., Sawhney, A., Iyler, K., & Rentala, S. (2012). Analysying factors affecting delays in Indian Construction projects. *International journal of project management* , 30 (4), 479 - 489.

Dunne, J. P., Stouffer, R. J., & John, J. G. (2013, February 24). Reductions in labour capacity from heat stress. *Nature Climate Change* , 6, pp. 563-566.

Dutta, P., Rajiva, A., & Andhare, D. (2015). Perceived heat stress and health effects on construction workers. Indian *Journal of Occupational and Environmental Medicine* , 19, 151 - 158.Frymoyer, J., & Mooney, V. (1986). Current concepts review, occupational orthopaedics.J. Bone Joint Surg. 68A., (pp. 469 - 474.).

Ebole A.J. (2005).Materials management on construction projects: Acase study on concreting works on sites in Nairobi. *University of Nairobi, College of Architecture and Engineering* (CAE) [1260]

Environment and Climate Change Canada. (2013) Retrieved August 25, 2020, from ec.gc.ca: https://ec.gc.ca/meteo-weather/meteo-weather/default.asp?lang=En&n=6C5D4990-1

Fryer, D. & Payne, R. (1984). Working definitions. Quality of Working Life, 1(5), pp. 13-15.

Gaspher, A. & Quintela D. (2009). Physical modelling of globe and natural wet bulb temperatures to predict WBGT heat stress index in outdoor environments. Int J Biometeorol. 53: 221 - 30.

Government of Kenya (2010) National Climate change response strategy. Ministry of Environment and Mineral Resources, Nairobi, Kenya.

Grimm C.T., Wagner N.K. (1974) Weather effects on mason productivity. *J. Constr. Div.; 100:*pp.19–35

Hancher, D. E., & Abdi-Elkhalek, H. A. (1998). The effect of hot weather on construction labor productivity and costs. *Cost Eng.* 40 (4), 32 - 36.

Heppner, P., Wampold, B., & Kivlighan, D. (2008). *Research design in Counselling* (3rd ed.). Thomson Brooks/Cole.

Ilmarinen J. (2004). Past, Present and Future of Work Ability. In: Ilmarinen J, Lehtinen S, editors. *People and Work – Research Reports 65.* Finland: Finnish Institute of Occupational Health; 132–4.

International Labour Organisation. (2013). National Profile on Occupational Safety and Health – Kenya. Geneva: International Labour Office.

International Labour Organisation. (2019). *Working on a warmer Planet. The Impact of heat stress on labour productivity and decent work*. Geneva: International Labour Office.

Israel, G. D. (1992, October.). Sampling the Evidence of Extension. *Program Evaluation and Organizational Development, IFAS, University of Florida. PEOD-5* .

Kabir S. M. S. (2016). *Basic Guidelines for Research: An Introductory Approach for All Disciplines(1st Ed).* Book Zone Publication, Chittagong-4203, Bangladesh

Kathuri, J. N., & Pals, D. A. (1983). *Introduction to educational research*. Njoro Egerton University.

Kjellstrom, T., Freyberg, C., Lemke, B. (2018) Estimating population heat exposure and impacts on working people in conjunction with climate change. *Int J Biometeorol* 62, 291–306

Kothari , C. (2004). *Research Methodology: Methods and Techniques (2nd Revised Ed.).* New Delhi, India: International (P) Ltd.

Kothari, C. (1985). *Research Methodology-Methods and Techniques.* New Delhi: Wiley Eastern Limited.

Krejcie, R.V., & Morgan, D.W., (1970). Determining Sample Size for Research Activities. *Educational and Psychological Measurement.*Small-Sample Techniques (1960). *The NEA Research Bulletin*, Vol. 38.

Kuras, E. R., Richardson, M. B., Calkins, M. M., Ebi, K. L., Hess, J. J., Kintziger, K. W., Jagger, M. A., Middel, A., Scott, A. A., Spector, J. T., Uejio, C. K., Vanos, J. K., Zaitchik, B. F., Gohlke, J. M., & Hondula, D. M. (2017). Opportunities and Challenges for Personal Heat Exposure Research. *Environmental health perspectives,* 125(8), 085001. https://doi.org/10.1289/EHP556

Lamka, A. H. (2015). *semanticscholar.org.* Retrieved February 29, 2020, from https://pdfs.semanticscholar.org: https://pdfs.semanticscholar.org/7802/4083f6d60cf45873e5339233cccbb1a624c0.pdf

Li, B., & Baldwin, A. (2018). Meeting the challenge of climatic heat stress in construction. *Industrial Health* , 56 (4), 275 - 277.

Maxwell, J. A. (1996). *Qualitative research design: An interactive approach* (3rd ed., Vol. 41). California: Sage Publications, Inc.

Ministry of Health, Republic of Kenya (2015), *Basic Occupational Health and Safety Training Manual for Health Care Services in Kenya.* Nairobi, Kenya.

Mitullah, W.V. and Wachira, N.I. (2003) Informal Labour in the Construction Industry in Kenya: A Case Study of Nairobi. *ILO Sectoral Activities Programme Working Paper 204*, Geneva.

Mohamed, S., & Srinavin, K. (2002). Thermal Environment Effects on Construction workers' productivity. *ABI/INFORM Global* , 297.

Mugenda, O., & Mugenda, A. (2003). *Research methods Quantitative and Qualitative approaches.* Nairobi, Kenya: Act press.

Muema, L.M. (2016) Evaluation of personal protective clothing equipment utilization among construction workers in Mombasa, Kenya: *Jomo Kenyatta University of Agriculture and Technology,* JKUAT.

National Institute for Occupational Safety and Health(NIOSH). (2004). workers health chartbook 2004. Washington, D.C: NIOSH Publication No. 2004-146.

Ndegwa K.F. (2017).Labour productivity and performance of building projects in Nairobi County, kenya. *Kenyatta University, https://ir-library.ku.ac.ke/*

NCA. (2014). *https://nca.go.ke/wp-content/uploads/2017/05/Construction-Industry-Survey-Report-2014.pdf.* Retrieved June 18, 2020, from https://nca.go.ke: https://nca.go.ke/wp-content/uploads/2017/05/Construction-Industry-Survey-Report-2014.pdf

NIOSH. (2016). *NIOSH criteria for a recommended standard: occupational exposure to heat and hot environments*. (Vol. 106). National Institute for Occupational Safety and Health.

Occupational Health and Safety Council of Ontario. (2009). *Heat Stress Awareness Guide.* Workplace Safety and Insurance Board (WSIB), Ontario. Canada: 5252A

Occupational Safety and Health Act(OSHA). (2007). *Application of Act.* Nairobi: Government Printer.

Occupational Safety and Health Administration. (2013, May 30). *OSHA News Release - Region 4*. Retrieved February 29, 2020, from. osha.gov: https://www.osha.gov/news/newsreleases/region4/05302013

OSHA Canada. (2020). *dir.ca.gov* Retrieved April 10, 2020, from https://www.dir.ca.gov/dosh/doshreg/Heat-illness-prevention-indoors/heat-tlv.pdf..

OSHA. US. (2020, April 2020). *osha.gov*. Retrieved April 10, 2020, from https://www.osha.gov/dts/osta/otm/otm_iii/otm_iii_4.html.

Pennstate University. (2020, April 12). *extension.psu.edu*. Retrieved April 12, 2020, from https://extension.psu.edu/psychrometric-chart-use.

QuestionPro. (2021, 01 01). *questionpro.com*. Retrieved 03 12, 2021, from www.questionpro.com: https://www.questionpro.com/blog/non-probability-sampling/

Rameezdeen, R., & Elmualim, A. (2017). The Impact of Heat Waves on Occurrence and Severity of Construction Accidents. *International journal of environmental research and public health*, *14*(1), 70.

Ramsey J.D., Beshir M.Y. (2003). Thermal standards and measurement techniques.In: DiNardi SR, ed. *The occupational environment: its evaluation and control. 2nd ed*. Cincinnati, OH: American Industrial Hygiene Association.

Reardon C., McGee C., Milne G. (2020, April 11). Your Home: Australia's guide to environmentally friendly homes. Government of Australia. *https://www.yourhome.gov.au/passive-design/thermal-mass*

Rowlinson, S., Yunyanjia, A., Li, B., & Chuanjingju, C. (2014). Management of climatic heat stress risk in construction: a review of practices, methodologies, and future research. 66, 187–98.

Rubin, A., & Babbie, E. (2010). *Research Methods for social work(7th ed.)*. Belmont, CA: Brooks Cole.

Russo, S., Marchese, A. F., Sillmann, J., & Immé, G. (2016, May 12). When will unusual heat waves become normal in a warming Africa? *Environmental Research Letters* , 11 (5).

Sacred Heart University Library. (2020, April 11). *sacredheart.edu*. Retrieved April 11, 2020, from https://library.sacredheart.edu/c.php?g=29803&p=185902.

Saunders, M., Lewis , P., & Thornhill, A. (2003). *Research Methods for business students(3rd Ed.)*. Harlow, England: Prentice Hall.

Sawka, M. (2015). Heat acclimatization to improve athletic performance in warm-hot environments. *Gatorade Sports Sci Exchange* , 28, 1 - 6.

Shehata, M. E., & El-Gohary, K. M. (2012). Towards improving construction labor productivity. *Alexandria Engineering Journal* , 50, 321 - 330.

SteveRowlinson, & Jia, Y. A. (2015). Construction accident causality: An institutional analysis of heat illness incidents on site. *Annals of Occupation Hygiene* , 326 - 339.

test-and-measurement-world.com. Retrieved July 21, 2020, from *test-and-measurement-world.com*: https://www.test-and-measurement-world.com/Terminology/Relative-Humidity-Table-or-Chart.html#

University of Virginia. (2018, May 10). *news.virginia.edu*. Retrieved March 1, 2020, from https://news.virginia.edu: https://news.virginia.edu/content/study-unbearable-heat-stress-affect-east-africans-late-21st-century-0

USA Dept of Commerce. (2020, April 10). *weather.gov*. Retrieved April 10, 2020, from https://www.weather.gov/safety/heat-index

Wilson, L., Black, D., & Veitch, C. (2011). Heatwaves and the elderly - The role of the GP in reducing morbidity. *Australian family physician*, 40(8), 637–640.

Xiang, J., Bi, P., Pisaniello, D., & Hansen, A. (2014). Health Impacts of Workplace Heat Exposure: An Epidemiological Review. *Industrial Health* , 52, 91 - 101.

Yaglou, C. P., & Minard, D. (1957). Control of Heat Casualties at Military Training Centers. *Archives of Industrial Health* , 16 (4), 302-316.

Yi, W., & Chan, A. P. (2014). Critical Review of Labor Productivity Research in Construction *Journals. Journal of Management in Engineering* , 30 (2), 214-225.

Yi, W., & Chan, A. P. (2017). Effects of Heat Stress on Construction Labor Productivity in Hong Kong. A case study of Rebar workers. *International Journal of Environmental Research and Public Health* , 14 (1055).

Williams, N. (2017). The Borg Rating of Perceived Exertion (RPE) scale. *Occupational Medicine,* 67(5), 404-405.

Zhang, Y., Zhang, J., Chen, H., Du, X., & Meng, Q. (2014). Effects of step changes of temperature and humidity on human responses of people in hot-humid area of China. *Building and Environment* , 80, 174–183.

Zhao, J., Zhu, N., & Lu, S. (2009). Productivity model in hot and humid environment based on heat tolerance time. *Building and Environment* , 2202 - 2207.

APPENDICES

Appendix I: RESEARCH APPLICATION LETTER FOR DATA COLLECTION

PHILLIP OTIENO GENO KOTENG

P.O. Box 54378 – 00200,
Nairobi, Kenya
Tel: +254 727759900
E. mail: phillip.koteng@jkuat.ac.ke

B53/81528/2015

Date: 7th October 2020

The Chairperson,
Department of Construction Management and Quantity Surveying,
P. O. BOX 30197-00100.

Dear Sir/Madam,

RE: Request for a letter to undertake research in Mombasa_BBE514.

I am a post-graduate student undertaking Master of Arts in Construction Management.

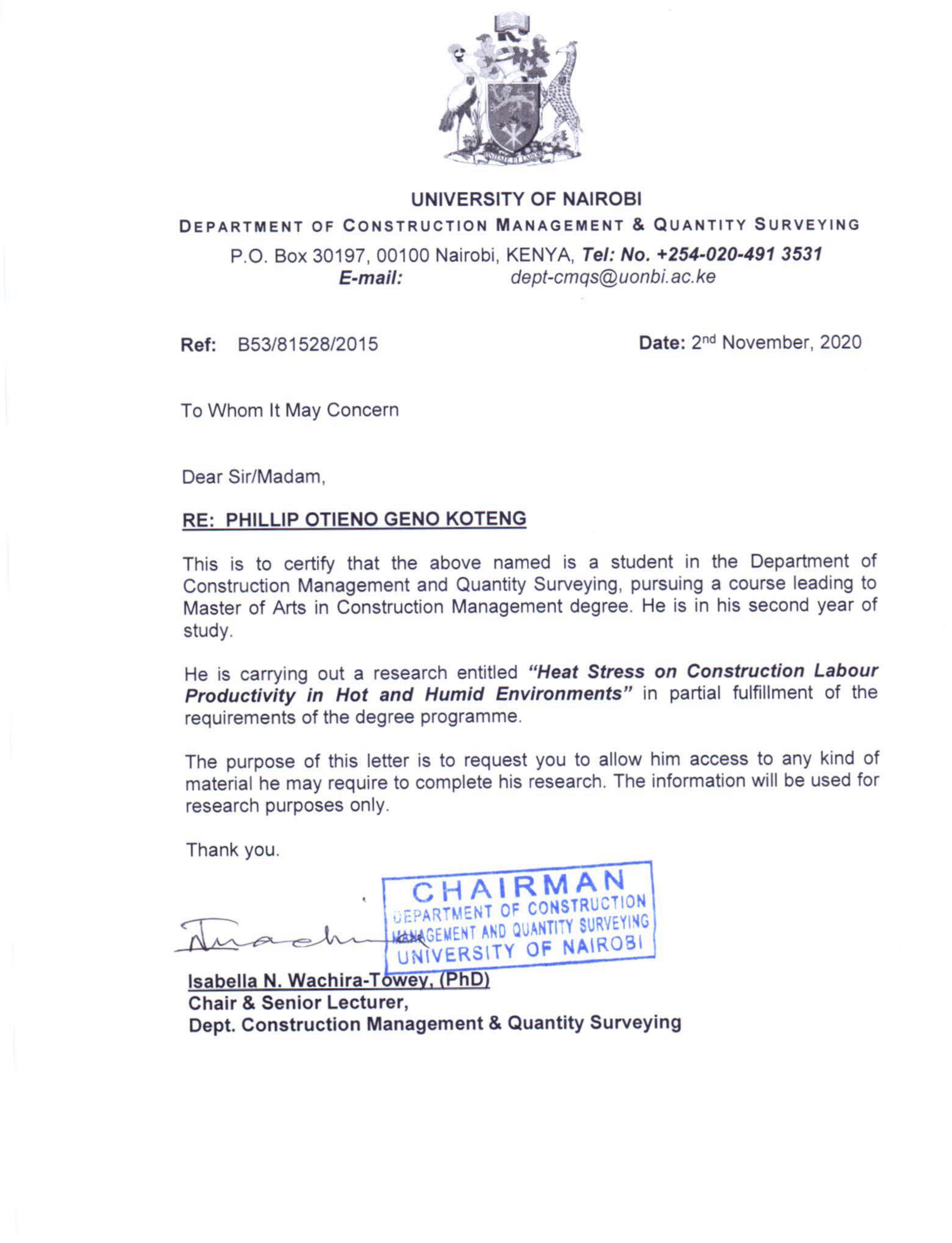
I am humbly requesting the Department for a letter which will enable me to undertake field studies in Mombasa in the unit BBE 514: Research Project. My project is titled **Assessment of Heat Stress Exposure on Construction workers in Hot and Humid Environments**.

My supervisor is Dr. Anthony Ralwala and he has given me the permission to undertake the field study.

Yours faithfully,

Phillip Koteng
B53/81528/2015

Appendix II: INTRODUCTION LETTER FROM THE DEPARTMENT



UNIVERSITY OF NAIROBI
DEPARTMENT OF CONSTRUCTION MANAGEMENT & QUANTITY SURVEYING
P.O. Box 30197, 00100 Nairobi, KENYA, ***Tel: No. +254-020-491 3531***
E-mail: *dept-cmqs@uonbi.ac.ke*

Ref: B53/81528/2015 **Date:** 2nd November, 2020

To Whom It May Concern

Dear Sir/Madam,

RE: PHILLIP OTIENO GENO KOTENG

This is to certify that the above named is a student in the Department of Construction Management and Quantity Surveying, pursuing a course leading to Master of Arts in Construction Management degree. He is in his second year of study.

He is carrying out a research entitled ***"Heat Stress on Construction Labour Productivity in Hot and Humid Environments"*** in partial fulfillment of the requirements of the degree programme.

The purpose of this letter is to request you to allow him access to any kind of material he may require to complete his research. The information will be used for research purposes only.

Thank you.

CHAIRMAN
DEPARTMENT OF CONSTRUCTION
MANAGEMENT AND QUANTITY SURVEYING
UNIVERSITY OF NAIROBI

Isabella N. Wachira-Towey, (PhD)
Chair & Senior Lecturer,
Dept. Construction Management & Quantity Surveying

Appendix III: PRE – STUDY DATA COLLECTION SHEET

UNIVERSITY OF NAIROBI

FACULTY OF THE BUILT ENVIRONMENT & DESIGN

DEPARTMENT OF REAL ESTATE, CONSTRUCTION MANAGEMENT AND QUANTITY SURVEYING

Introduction: This research is meant for academic purposes only. The data collected herein will aim to assess the heat stress levels of construction workers in Mombasa. Responses are treated as confidential.

This pre-study data sheet to be completed by the **researcher or study assistant**

SECTION A: BACKGROUND INFORMATION

RESEARCH:

Assessment of Heat Stress on Construction workers in Hot and Humid Environment

Data sheet No. : ______________________________

Construction worker No. : ______________________________

Job Description: ______________________________

Weight (kg):

SECTION B: PRE-STUDY INFORMATION

Voluntary Participation: Accepted: ☐ Not Accepted: ☐

1. Please tick (✓) below the construction worker’s Age in years

☐ 18-30 ☐ 31-40 ☐ 0-50 ☐ 60

2. Please tick (✓) below the construction workers gender

☐Male ☐emale

3. Record the construction workers body temperature before commencement of work.

Recorded body temperature (°C) ____________________________________

Acclimatization Check

4. Have you worked in Mombasa as a construction worker within the past two weeks

☐es

☐No

Clothing Check

5. Please tick (✓) below the construction workers clothing worn

☐PPE(coverall) ☐T-Shirt/shirt ☐Vest ☐No upper-body clothing
☐Trousers ☐Shorts ☐elmet ☐ead gear

Skill Level Check

6. Please tick (✓) below the construction workers skill level

☐Skilled (Fundi) ☐nskilled (Casual)

Appendix IV: DATA SHEET FOR RECORDING THE FREQUENCY OF EXPOSURE TO DIRECT SUN-LIGHT, PERCIEVED EXERTION AND WORKLOAD

Item	**Job title**	**Tasks/Activities observed**	**Exposure Levels**	**Perceived exertion** (Borg CR10 scale)	**Classification of workload** (ACGIH screening criteria)
1					
2					
3					
4					
5					
6					
7					
8					

Direct Sun Exposure Duration Rating

Direct Sun Exposure Duration Rating		
Duration	Description	Rating
2 hrs and above	Extremely High	4
1.5-2 hrs	High	3
1-1.5 hrs	Moderate	2
1hr or less	Low	1

Borg CR10 Scale

Borg CR10 scale	
Rating	Description
0	Rest
1	Very Easy
2	Easy
3	Moderate
4	Somewhat Hard
5	Hard
6	Hard
7	Very Hard
8	Very, very Hard
9	Nearly Maximal
10	Maximal

ACGIH Screening Criteria

ACGIH screening criteria	
Description	Rating
Light	1
Moderate	2
Heavy	3
Very Heavy	4