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How Heat Waves Influence Project Performance in the Construction Industry?

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Abstract

Heat waves in Southeast Asia are becoming increasingly common and intense, posing substantial challenges for the construction industry. As the heat waves are predicted to increase in the future, they will certainly impact construction project performance, specifically in terms of cost, time, and quality. This paper aimed to analyze the impact of heat waves on these project performances. A questionnaire survey using Microsoft Forms was used to gather the data. This paper focuses on 200 respondents from Grade 6 (G6) and Grade 7 (G7) contractors in Johor Bahru, Johor. The findings show the interrelated effects on time, cost, and quality. The productivity of workers decreased as they required a longer time to rest, which led to delay issues. Additionally, exposure of the material to heat and workers' focus on work influence the poor quality of the project. The heat forcing in additional safety measures and heat-related illnesses necessitate more labor, further escalating project costs. Therefore, the paper concludes that heat waves influence construction in Malaysia through an increased duration cost and risk of project completion associated with quality.

1. Intoduction

The construction sector is crucial to Malaysia's economy, making significant contributions to its GDP, employment, and overall economic activities. Recent research has highlighted this importance. Although the industry has rapidly expanded with the incorporation of new technologies and more structured processes, effective project management remains essential for integrating time, cost, and quality into construction projects. Nevertheless, challenges such as project delays, cost overruns, and quality issues persist due to risks and uncertainties brought on by unforeseen circumstances [1]. Additionally, there are various unrecognized risks associated with the construction industry, including an increased vulnerability to extreme weather events like heat waves [2].

In tropical regions like Malaysia, which are known for high humidity, heat waves have become more frequent and intense due to the effect of climate change [3]. According to a report by the National Disaster Management Agency (NADMA), Malaysia has recently experienced significant heat waves, with very high temperatures recorded in several states. As of early April 2024, areas such as Temerloh, Pahang and Gua Musang, Kelantan have reached a level two (2) heatwave status, indicating severe heat conditions. Other regions, including Perlis, Johor, Terengganu, Sabah, Sarawak, Negeri Sembilan, Kedah, and Perak, are facing level one (1) heatwave conditions. The report shows that studies on tropical climates are especially important because heat waves are predicted to increase in the future, having a substantial impact on the economy due to labour productivity, health, and project performance [4]. Recent trends show an increase in extreme weather events like these heat waves, which pose significant risks to construction projects. While previous research has primarily focused on the impact of heat

waves on labour productivity, there remains a crucial gap in understanding how these climate changes affect essential project management parameters such as time, cost, and quality [5]. This gap is particularly concerning given that heat waves can lead to increased project durations and costs while compromising the quality of construction projects.

Therefore, this paper is focused on the construction industry in Johor Bharu from the perspective of construction industry players such as project managers, site engineers, and site supervisors which aims to analyse the effect of heat waves of project management constraints in terms of time, cost, and quality. The primary objectives of this paper are (1) to identify the effects of heat waves on project management constraints and (2) to analyse the effect of heat waves on project management constraints based on the perception of construction industry players.

2. Construction Industry Overview

Construction industry describes as the industrial sector of production and trade that deals with infrastructure development, maintenance, and repair. Nowadays, construction is one of the main sectors of the Malaysian economy [1]. The construction industry is known for its unique characteristics, including its complex structure, intricate management processes, and diverse resources involved in a project's life cycle. Also, the construction industry is dynamic in structure due to increasing client expectations, technology improvement, time and budget constraints, and process development. In addition, the construction industry is diverse comprising various sectors specializing in different types of construction work. These sectors include residential construction, commercial construction, industrial construction, infrastructure, and external works [1]. Construction projects go through several stages from the beginning to the end, each with various duties intended to identify, plan, design, and build the planned building [6].

Generally, the responsibilities of the construction industry are multidimensional and characterized by a diverse range of players, each contributing to the successful delivery of construction projects [7]. These players, defined as individuals or entities involved in various responsibilities within the construction sector, contribute significantly to the industry's growth and sustainability. The construction industry involves a wide range of stakeholders including owners, developers, architects, engineers, contractors, subcontractors, suppliers, and government agencies. Each position plays a crucial role in the successful completion of construction projects. In Malaysia, the Construction Industry Development Board (CIDB) grades the contractors based on their capability to fulfil certain criteria. Contractors also can be classified into four categories which are the construction of the building (B), civil engineering construction (CE), mechanical and electrical (ME), and facility (F). CIDB registers construction enterprises on behalf of the Malaysian government, categorizing them into seven classes (G1-G7) [1].

2.1 Project Management Constraints

In project management, the concept of project constraints refers to the conventional limitations of quality, time, and cost that project managers must maintain a balance between to complete their scope of work. These constraints are sometimes referred to as iron triangle or triple constraints. This metaphor, which is frequently employed in the industry, emphasizes the project manager's comprehensive role in handling these interconnected limitations [8]. Project management constraint is often seen as a fundamental concept that represents the relationship between three primary objectives of a construction project which are time, cost, and quality [9]. These three objectives are interconnected, indicating that any changes to one element will directly affect the other elements as well [10]. By means of that, the project constraint consists of two interdependent variables. Independent variables consist of time, cost, and quality, meanwhile the dependent variable is the construction project, and the independent variable determines the effect of another variable on the relationship [11].

Research indicates that effective management of these constraints is essential for project success. However, many projects fail due to inadequate planning and oversight of these constraints [11]. The construction industry often struggles with these challenges because each project is unique in terms of scope, location, and resources involved [12].

2.2 Climate Change

Climate change has emerged as a significant challenge for various sectors worldwide, including the construction industry. One consequence of global warming is the increased frequency of extreme weather events such as heat waves, droughts, floods, cyclones, and wildfires [13]. In addition, one of the most pressing issues associated with climate change is the increase in extreme weather events such as heat waves. Recent studies indicate that heat waves are becoming more frequent and intense in Southeast Asia, raising concerns about their implications for construction projects [5].

Heat waves is generally defined as a period of abnormally high temperatures that lasts for an extended duration whether this event occurring several days or weeks, and one of the most threatening natural hazards

and can adversely affect the ecosystem, infrastructure, human health, and social life [13]. According to The World Meteorological Organization (WMO), heat waves are defined as 5 or more consecutive days of prolonged heat in which the daily maximum temperature is higher than the average maximum temperature by 5°C [14]. Heat waves can adversely affect project management constraints by leading to increased project duration and costs while compromising quality. For example, high temperatures can reduce worker productivity due to heat stress and fatigue. This decline in productivity often results in longer project timelines and increased labor costs as workers require more breaks or additional support to manage heat-related illnesses [5]. Furthermore, extreme heat can compromise material integrity and overall work quality, leading to potential long-term issues with durability and safety.

3. Methodology

This section outlines the research methodology employed to investigate the effects of heat waves on project management constraints—specifically time, cost, and quality—in the Malaysian construction industry. A mixed-method approach was adopted to gather comprehensive data from construction industry players.

3.1 Research Design

This study uses a mixed method approach, combining both qualitative and quantitative approaches to provide a holistic view of the effect of heat waves on construction projects. Qualitative data were collected through literature analysis to establish a theoretical framework and identify the gaps in current knowledge regarding heat waves and their effect on project management constraints [1][5]. Meanwhile, quantitative data was obtained through a structured questionnaire survey distributed to the G6 and G7 construction industry players in the Johor Bharu area. The estimated number of respondents for this study will be about 242 respondents. Then, the questionnaire was distributed to the G6 and G7 construction companies in Johor Bharu via company email through Google Mail (Gmail) to enhance data accuracy [15]. This survey aimed to gather valuable insights on how heat waves affect project time, cost, and quality from the perspective of construction industry players.

3.2 Research Instrument

A thorough literature analysis was conducted to investigate project management constraints, specifically focusing on time, cost, and quality. The impacts of heat waves on these constraints are particularly pertinent given their increasing prevalence in construction environments. By examining existing reports and project documentation, this study sought to clarify how heat waves affect construction projects [16]. This method served as a foundation for creating question items by breaking down the specific impacts of heat waves on project management constraints.

Then, the questionnaire is constructed using Microsoft Forms, an open online survey tool, and the results are stored in Microsoft Excel. The questionnaires are divided into 4 sections which correspond to the objectives of this study. Section A will cover the respondents' demographic information, Section B is to address the effects of heat waves on project time, Section C is to address the effect of heat waves on project cost and Section D is to address the effect of heat waves on project quality. Besides, the respondents need to give scores from range 1 to 5 where the range is from strongly disagree to strongly agree. In other words: 1- strongly disagree, 2- disagree, 3 – neutral, 4 – agree, and 5- strongly agree [17].

3.3 Validation of Instrument

Expert review is used by the researchers to a group of experts to review their questionnaires. This method is used to evaluate the relevance and clarity of the items within a research instrument [18]. The questionnaire was designed with considerations for feasibility, readability, and word clarity. Therefore, in this study, the questionnaire was validated through expert review by 3 academicians from Universiti Tun Hussein Onn Malaysia. The experts are from the same background and have experience in construction.

4. Data Analysis

Data analysis is a method of using logical and statistical methods to analyse the data obtained in the process. Descriptive analysis is a method to summarize and interpret the data derived from multiple choice and Likert scale questions. Furthermore, the index average classification of Likert scale responses provides additional insights into the level of agreement or disagreement expressed by participants.

4.1 Results and Data Analysis

There are 5 sections to discover the background of the respondents who participated in the survey. The questions that have been asked by the respondents are regarding their range of age, work experience, role in construction,

type of project experience, and grade of contractor according to the Construction Industry Development Board (CIDB). The questionnaire comprised 200 respondents, and the information gathered from this population was crucial in understanding the characteristics of the respondents.

The demographic data of the study involved 200 respondents with notable characteristics. The majority were aged 21–30 years (44%) and 31–40 years (46%), indicating a younger workforce, while only 3% were under 20 and 7% were over 40. In terms of work experience, 44% had 11–20 years, followed by 36% with 6–10 years. Most respondents (55%) identified as site managers or supervisors, with project engineers at 29.5%. The types of projects primarily involved residential and infrastructure work (44% each), and contractor classifications showed that 67% were Grade G6, handling medium-scale projects, while about one-third were Grade G7 for larger projects.

4.2 Literature Analysis for Question Item Design

Based on this sub-section, literature analysis was utilized to identify the critical factors influenced by heat waves that can disrupt construction projects including their effects on time, cost, and quality. Table 1 summarises the key aspects, factors, and descriptions derived from past research to outline the core challenges posed by extreme temperature in project management constraints. These factors serve as the foundation for the creation of question items that measure the extent of the effect of heat waves in the construction industry.

Table 1 *Factor aspects of the effect of heat waves*

Aspect	Factor	Description
Time	Increased Breaks/Sick Leave [4][19][20]	Heat waves lead to more frequent breaks and higher absenteeism due to health issues, extending project timelines.
	Work Schedule Adjustments [2][30]	Adjustments are necessary to avoid working during peak heat hours, which can prolong project durations.
	Project Scheduling [1][2][6]	Adverse weather conditions cause unexpected delays that necessitate changes in project scheduling.
	Increased Time for Task Completion [16][20][29]	Frequent breaks and slower work rates due to heat stress can lead to longer task completion times, impacting overall project timelines
	Diminished Work Capacity [1][24][28]	Extreme heat reduces labour capacity, leading to significant delays in project timelines.
Cost	Economic Losses [12][23][24]	Heat-induced reductions in productivity can lead to substantial economic impacts on project budgets, with estimates indicating significant losses during extreme heat events.
	Increased Project Cost [5][23][26]	Extended project durations due to heat-related delays and necessary safety measures increase overall project costs significantly.
	Higher Labor Costs [8][19][28]	The need for additional cooling equipment and extended working hours can raise labour costs, further straining project budgets.
	Compensation Claims [6][7][28]	Increased incidents of heat-related illnesses lead to higher compensation claims and associated costs for employers, impacting overall project finances.

Aspect	Factor	Description
Quality	Heat Stress Impact on Quality [1][4][15]	Prolonged exposure to high temperatures compromises work quality, leading to increased error rates.
	Deterioration of Building Materials [21][22][29]	Extreme heat negatively affects the quality and integrity of construction materials, such as concrete and steel.
	Health Risks/Fatalities [16][20][28]	The risk of heat-related illnesses among workers can lead to lower quality output due to fatigue and health issues.
	Reduced Worker Performance [2][4][24]	Heat stress leads to decreased concentration and efficiency among workers, negatively impacting task quality.

4.3 Analysis of Effects of Heat Waves on Project Time

Based on this sub-section, there were 6 statements from respondents to select based on their opinions regarding their awareness of the effect of heat waves on project time in construction projects. This section used the Likert scale range from strongly disagree to strongly agree. Table 2 shows the percentage of the Likert scale for the time aspect based on the perspective of the construction industry players.

Table 2 *Percentage of the Likert scale for time perception*

No.	Element	Strongly Disagree (%)	Disagree (%)	Neutral (%)	Agree (%)	Strongly Agree (%)
1	Extreme temperatures lead to increased project delays in construction timelines.	1	0.5	3	90	5.5
2	Workers tends to take more breaks during heat waves, impacting project timelines	1	10.5	24.5	58	6
3	Workers need to take sick leave due to heat-induced injuries	1	19.5	25	49	5.5
4	Construction schedules need to be adjusted to avoid working during peak heat hours	1	13.5	30	51.5	4
5	High temperatures cause frequent equipment malfunction impacting project schedules	1	2.5	24	69	3.5
6	The quality of materials used in construction is compromised by extreme heat, leading to delays.	1	2	11.5	80	5.5

The survey results highlighted the perceptions of the majority of respondents regarding the significant time scheduling impacts of heat waves on construction projects. Notably, most of the respondents-90% agreed that high temperatures lead to project delays, while 58% acknowledge that workers tend to take more breaks during heat waves, further affecting schedule disruptions. Extreme temperatures can significantly hinder construction activities [19]. Additionally, heat exposure leads to productivity loss among construction workers, emphasizing that prolonged exposure to high temperatures necessitates longer breaks ranging from 10-40 minutes per hour of active work, reducing overall work efficiency [20].

Furthermore, 51.5% agree that construction schedules need adjustments to avoid peak heat hours, and 69% believe high temperatures cause frequent equipment malfunctions, disrupting project timelines. Also, material quality is a concern, with 80% agreeing that extreme heat compromises materials, leading to delays. Extreme heat not only impacts the physical properties of building materials but also necessitates an impact on several aspects of building performance, with much of the actual and future building stock likely to be affected [21]. Besides, high temperatures influence the performance and durability of various building materials and the need for specific building materials to cool or cure properly under extreme heat can significantly delay project timelines [22]. These findings underscore the urgent need to implement timely and effective heat-resilient strategies in construction projects.

4.4 Analysis of Effects of Heat Waves on Project Cost

Based on this sub-section, there were 7 statements from respondents to select based on their opinions towards their awareness of the effect of heat waves on project cost in construction projects. This section used the Likert scale range from strongly disagree to strongly agree. Table 3 shows the percentage of the Likert scale for the cost aspect based on the perspective of the construction industry players.

Table 3 *Percentage of the Likert scale for cost perception*

No.	Element	Strongly Disagree (%)	Disagree (%)	Neutral (%)	Agree (%)	Strongly Agree (%)
1	Heat waves increase the overall cost of your projects	1.5	0.5	4.5	90	3.5
2	Heat waves lead to increased construction costs due to project delays.	1	2.5	27.5	65	4
3	Heat waves will cause the construction Industry to suffer financially due to decreased labour availability	1.5	1.5	20.5	69.5	7
4	Heat waves will affect project profitability	1	2	18	70.5	8.5
5	Heat waves causing an increase in material cost	1.5	18	29.5	46	5
6	Heat waves will necessitate project financing adjustments due to extreme conditions	1	10	32	54	3
7	Heat waves will continue to impact the construction industry economically in the future	1.5	1	6	80.5	11

The survey results highlighted the perceptions of the majority of respondents regarding the significant economic impacts of heat waves on construction projects. Many respondents with 90% agree that heat waves increase the overall cost of projects, while 65% agree that these conditions lead to increased construction costs due to project delays. The primary reasons identified for these increased costs include delays in work schedules, diminished productivity among workers, and the necessity for implementing additional safety measures to protect personnel from HRIs. In addition, heat-induced reduction in worker productivity leads to substantial economic costs globally [23]. 45% of all construction projects are affected by weather-related issues, resulting in billions of dollars in additional costs globally [19].

Furthermore, 69.5% agree that heat waves cause financial strain on the construction industry due to decreased labour availability, and 70.5% believe they negatively affect project profitability. This indicated that the economic implications of heat-related illnesses are substantial as labour productivity losses range from 11% to 27% [24]. Therefore, it leads to the financial burden that extends beyond immediate productivity losses including increased operational costs related to healthcare and emergency services [24].

Material costs are also affected, with 46% agreeing that heat waves cause an increase in material costs, and 54% agreeing that extreme conditions necessitate project financing adjustments. Heat waves can also cause physical damage to infrastructure such as roads and bridges, which are especially vulnerable since high temperatures can lead to expansion and contraction, resulting in cracks and structural failure [25]. Also, the research emphasizes the importance of planning and financial adjustment to cope with extreme temperatures [26]. Finally, 80.5% of the respondents agree that heat waves will continue to economically impact the construction industry in the future. As heat waves become more frequent and severe, they can lead to increased project delays, heightened labour costs, and reduced worker productivity due to safety concerns. These findings emphasize the pressing need for financial and operational strategies to mitigate the adverse effects of extreme heat on construction projects.

4.5 Analysis of Effects of Heat Waves on Project Quality

Based on this sub-section, there were 9 statements from respondents to select based on their opinions towards their awareness of the effect of heat waves on project quality in construction projects. This section used the Likert

scale range from strongly disagree to strongly agree. Table 4 shows the percentage of the Likert scale for quality aspect based on the perspective of the construction industry players.

Table 4 *Percentage of the Likert scale for quality perception*

No.	Element	Strongly Disagree (%)	Disagree (%)	Neutral (%)	Agree (%)	Strongly Agree (%)
1	Heat waves significantly reduce the Overall productivity of construction projects	1	0	6	89.5	3.5
2	The quality of work decreases when the construction is performed during heat waves	1	1	30	66.5	1.5
3	The likelihood of accidents on construction sites increases during heat waves	1.5	12	22	57	7.5
4	High temperature affects the quality of construction materials	1	2	26	66	5
5	Heat waves increase worker absenteeism	1	17	30.5	42.5	3.6
6	Heat waves hinder team collaboration and communication	6.5	26.5	24.5	40	2.5
7	Heat waves conditions challenge the quality control and assurance	1	1	21	72,5	4.5
8	Heat waves affect the storage condition of construction materials	1	2.5	21	71	4.5
9	To what extent do you agree that heat waves significantly impact the health of workers?	1	0	8.5	84.5	6

The survey results highlighted the perceptions of the majority of respondents regarding the significant quality impacts of heat waves on construction projects. Most respondents, 89.5% agree that heat waves reduce overall productivity, while 66.5% agree that the quality of work decreases when construction is performed during heat waves. The study emphasizes that heat waves can lead to increased fatigue among workers, resulting in slower work rates and potential safety hazards resulting in reducing overall labour productivity in construction projects [27]. Additionally, 57% agree that the likelihood of accidents increases on construction sites under such conditions. Extreme temperatures can negatively impact on the workers, highlighting the role of fatigue, dehydration, and heat-related illnesses leading to an increased likelihood of errors or accidents, which can compromise the integrity of construction projects [28].

Furthermore, high temperatures also impact material quality, with 66% agreeing that it is negatively affected, and 72.5% highlighting challenges in maintaining quality control and assurance. Thermal properties of building materials must be considered to enhance durability and performance in hot climates as heat exposure can alter material properties, reducing strength and durability. For example, concrete may lose strength and experience explosive spalling under high temperatures, exposing reinforcing steel to damage and leading to inconsistencies in product strength and durability [22]. This indicated that the integrity of materials will significantly affect quality control and assurance, as materials can lead to failures in meeting project specifications and standards, ultimately impacting the overall success of the construction project.

Moreover, 71% agree that heat waves affect the storage conditions of construction materials, and 84.5% acknowledge the significant impact of heat waves on workers' health. Materials such as concrete and asphalt can lose compressive strength and soften under high temperatures, compromising their performance and durability [29]. Also, workers' health can be affected by exposure to extreme heat can lead to various physiological impacts on construction workers, including heat exhaustion and heat stroke, which are serious health risks that can result from prolonged exposure to high temperatures [30]. Lastly, responses regarding increased worker absenteeism and hindered team collaboration are less conclusive, with 42.5% and 40% agreeing, respectively. Extreme heat contributes to fatigue, irritability, and reduced cognitive function, creating a tension between productivity and respect for individuals in construction, as environmental factors like heat stress can adversely affect worker

interactions and overall performance [31]. These findings emphasize the pressing need for measures to mitigate heat wave impacts on construction productivity, safety, and material quality.

5. Discussion

Heat waves have a significant impact on construction projects, causing delays, higher costs, and reduced quality. Respondents stated that heat waves induce worker tiredness, longer breaks, and equipment problems, all of which impair project schedules. Research supports these findings, revealing that heat stress reduces productivity and requires longer break times. In addition, cost increases are linked to the necessity for improved safety measures, longer project durations, and material deterioration, while labor shortages increase expenses. Also, high temperatures degrade material characteristics and lower workmanship quality, affecting quality control efforts. Hence, these difficulties are interconnected within the framework of project management constraints which are time, cost, and quality with delays increasing costs and compromised quality extending both schedules and budgets. To effectively negotiate these interconnected constraints, construction companies should use flexible scheduling strategies, invest in sustainable materials, implement cost-effective safety standards, and prioritize comprehensive planning that considers time, cost, and quality.

6. Conclusion & Recommendation

In conclusion, the study highlights the pressing challenges that heat waves pose to project management constraints such as time, cost, and quality. The value of a holistic approach to addressing these as climate change continues to force construction industry players to make those changes. By using climate risk assessment, planning, and working with climate-resilient materials, the construction industry is already adapting to the adverse effects of extreme heat, particularly heat waves.

In addition, the implementation of flexible scheduling practices coupled with worker-first safety initiatives such as hydration stations and protective gear are effective means to mitigate health risks while improving workforce productivity in totality. Backing these would be more advanced technological advances, for example,in the form of predictive analytics and real-time monitoring systems, which would go a long way in empowering decision-makers to effect proactive adjustments based on evolving conditions.

Finally, management needs to be balanced and recognize that any move to alleviate one constraint will always affect the others. This would require turning heat-related problems into opportunities for increased resilience and growth through collaboration among construction players and increased investment in research and innovation. By embracing sustainable practices within the project management framework, the construction industry can realize operational efficiency with sustainability for long-term success in an increasingly challenging environment.

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Conflict of Interest

Authors declare that there is no conflict of interests regarding the publication of the paper.

Author Contribution

The author confirms sole responsibility for the following: study conception and design, data collection, analysis and interpretation of results, and manuscript preparation.

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