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IMPACT OF EXTREME CLIMATE CONDITIONS ON THE SAFETY OF CONSTRUCTION WORKERS

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Abstract

The safety performance of construction projects is significantly impacted by extreme weather conditions, including excessive heat and cold. In the United States, while general safety regulations are in place to protect construction workers, specific clauses addressing the challenges posed by varying climatic conditions remain absent. It is crucial for project management teams to proactively safeguard their workforce against weather-related health risks.This report examines the physical and mental effects of extreme climate conditions on construction workers from diverse backgrounds and identifies current preventive measures adopted within the industry. Furthermore, it proposes strategies to mitigate these impacts, supported by a detailed case study. The insights presented aim to advance sustainable safety practices and enhance worker productivity in the face of extreme weather challenges (Moohialdin et al., 2022; Karthick et al., n.d.).

Keywords: Construction Safety, Extreme Weather Conditions, Heat Exposure, Cold Exposure, Sustainable Safety, Risk Mitigation, Climate Adaption, Labor Productivity, Climate Effect, Workforce Health.

I. INTRODUCTION

The construction industry employs a substantial workforce globally, with workers actively engaged in all phases of projects and performing diverse activities throughout the year. These activities often expose them to varying weather conditions that can lead to injuries, accidents, and health issues on-site (Karthick et al., 2020).Extreme weather conditions, such as excessive heat or cold, directly and indirectly impact construction workers, leading to reduced productivity, delays in project schedules, and increased costs. This study underscores the necessity of analyzing how climatic conditions influence construction performance and exploring mitigation strategies (Sanjgna et al., 2020).

While the human body can thermoregulate within a core temperature range of 35°F to 40°F, prolonged exposure to extreme temperatures inhibits its ability to maintain internal equilibrium (Karthick et al., 2020). Such exposure often results in severe physical conditions, including heat strokes, organ damage, and impaired physiological function. Research forecasts a sharp rise in

heat stress cases by 2030, with a 300% increase anticipated by 2100 (Sanjgna et al., 2020). Cold weather-related issues, such as frostbite, cold stress, and numbness in exposed areas, are equally concerning and demand attention (Karthick et al., 2020).

Despite the adverse effects of working under extreme weather conditions, studies addressing their impact on construction processes remain limited. Factors such as worker acclimatization, gender, age, hydration levels, wind speed, and humidity influence the severity of climatic impacts (Ammar et al., 2021). Current guidelines from the Occupational Safety and Health Administration (OSHA) suggest general measures such as ensuring hydration, rest periods in hot climates, and protective clothing in cold conditions. However, the absence of formal regulations addressing these issues has led to worker injuries and illnesses in projects where prevention strategies were not adopted.

The objective of this study is to analyses the challenges posed by extreme weather conditions on construction workers and processes, propose strategies to address these challenges, and identify avenues for further research to enhance safety practices.

II. STATE OF PRACTICE

The execution of construction activities varies significantly across countries due to differences in standards, methods, and regulatory frameworks. The working environment and conditions in construction projects are also influenced by topographical and climatic variations, which present unique challenges to workers. Many construction workers frequently travel across states or international borders to work on projects, exposing them to unfamiliar weather conditions.

Some nations enforce stringent safety guidelines to protect workers, whereas others lack robust implementation of preventive measures to mitigate the effects of extreme climate conditions. Consequently, it is challenging to generalize the impact of weather-related challenges across the global construction industry. Nonetheless, research has identified common trends and challenges, offering valuable insights into how weather conditions affect workers across various project phases.

1. Vulnerable Communities

The construction industry employs a diverse workforce, often comprising individuals who migrate to different regions or countries for employment. These migrant workers are typically not acclimatized to the local climate, making them highly vulnerable to heat and cold stress (Karthick et al., 2020). Despite the demanding and often harsh field conditions, workers with pre-existing health conditions or physical vulnerabilities are frequently assigned to strenuous tasks, further increasing their susceptibility to weather-induced illnesses and injuries.

2. Health impacts

Workers with pre-existing health conditions, such as hypertension, are disproportionately affected by extreme heat. Without adequate hydration or sweating, these individuals are at heightened risk of heat exhaustion, which can escalate into severe health complications. Similarly, older workers (particularly those aged 50 and above) are more vulnerable to climate stressors, often experiencing irritation, distraction, and accidents due to the discomfort caused by extreme temperatures.

In cold climates, workers may encounter muscle fatigue from wearing tight or cumbersome thermal clothing, which can lead to hallucinations and disorientation under prolonged exposure. High pollution levels at construction sites, combined with hot weather and strong winds, exacerbate respiratory conditions, such as asthma and chronic lung disease. Smokers are particularly at risk of developing severe illnesses compared to their non-smoking counterparts (Karthick et al., 2020).

Delayed physiological responses are another consequence of exposure to extreme weather. This can manifest as impaired coordination, reduced judgment when handling tools, and increased risk of accidents (Sanjgna et al., 2020). Emotional distress, including anxiety and depression, is also prevalent among construction workers in harsh conditions. Alarmingly, studies have linked mental stress and extreme climate conditions to elevated suicide rates, particularly among transportation workers who operate in remote and resource-scarce environments (Sanjgna et al., 2021). Scaffolders, steel fixers, and form workers are similarly challenged by physiological adjustments required for working at heights under extreme conditions.

In the Middle East, the overlap of high summer temperatures and the month of Ramadan poses unique challenges. Muslim workers fasting during this period may face dehydration, fluctuations in weight and blood pressure, altered body mass index, and disruptions in core body temperature and glucose levels—all of which compound the health risks associated with extreme heat (Ammar et al., 2021).

3. Productivity

Project productivity is typically evaluated based on factors such as time, budget, feasibility analysis, and labor performance. However, the impact of weather conditions on construction workers' productivity is often overlooked. Many projects lack adequate facilities or preventive measures to mitigate the effects of extreme hot or cold climates on-site. This negligence frequently results in worker illnesses and injuries, causing project delays and escalating construction costs over time.

In highway construction projects, which involve rapid renewal works within limited timeframes, workers must carry out multiple activities under challenging conditions. Extreme heat often leads to cognitive impairments and localized muscle fatigue, reducing overall productivity (Sanjgna et al., 2021).

Currently, a variety of economic and mathematical methods are employed to optimize construction management, including linear programming, inventory management, dynamic programming, game theory, network analysis, and simulation models. However, these approaches rarely account for the influence of weather conditions or their correlation with worker productivity (Vadim et al., 2019). There is a pressing need to integrate mathematical models into the planning phase to design effective work-rest schedules that enhance efficiency and labor productivity in extreme climates.

4. Unreported injuries

A prevalent issue in the construction industry is the underreporting of climate-related injuries. Heat-related injuries are often misrepresented or overshadowed by other existing health conditions in workers. In many cases, these injuries are minor enough for workers to recover within a day or two without hospitalization, resulting in their exclusion from formal records. Consequently, heat or cold-related injuries often go unreported or misclassified, preventing workers from claiming compensation (Jianjun et al., 2013).This issue is compounded by the lack of a distinct classification system for illnesses and injuries caused by extreme weather conditions. The absence of clear reporting protocols not only obscures the true extent of the problem but also limits the industry's ability to implement targeted preventive measures.

5. Data collection

The collection of safety performance indicators on construction sites is often manual and prone to inaccuracies, relying heavily on subjective opinions from workers. Such methodologies are limited in scope and often fail to capture real-time data. Additionally, manual data collection is typically performed infrequently, often only once or twice a month, which restricts the ability to identify and address climate-related impacts effectively.To mitigate the effects of extreme weather conditions on workers, there is an urgent need for a more efficient and continuous data monitoring system. Automating this process would not only improve the accuracy and timeliness of data collection but also enhance overall project efficiency and safety performance (Ibukun et al., 2018). Advanced technologies such as IoT-enabled sensors, AI-driven analytics, and cloud-based platforms could play a crucial role in revolutionizing safety and productivity management on construction sites.

6. Current practices on the construction site

To mitigate the impacts of extreme weather conditions on construction sites, a range of preventive strategies is commonly employed to safeguard equipment, materials, and workers. For equipment and materials, practices such as wetting construction materials to prevent dust, regularly replacing equipment filters, and applying anti-freezing solutions enhance performance and durability under harsh environmental conditions.For worker safety, several measures are implemented to address the challenges posed by extreme climates. These include encouraging the use of masks and protective shades, applying cold water sprays in hot environments, and ensuring frequent hydration to prevent heat-related illnesses. In cold climates, workers are advised to layer clothing appropriately and use thermal gear to maintain comfort and productivity.

Improving the understanding of at-risk worker groups, including those with pre-existing conditions or limited acclimatization to local climates, is critical in preventing heat- and cold-related illnesses and injuries. A proactive focus on these vulnerable groups can help in implementing tailored safety measures and avoiding preventable health complications (Amin et al., 2018; Jianjun et al., 2013).

III. CASE STUDY

Evaluating the impacts of high-temperature outdoor working environments on construction labour productivity in China (Xiaodong et al., 2015).This case study investigates the productivity of construction labourers working in high-temperature outdoor environments. Productivity data, categorized into direct work time, indirect work time, and idle time, was measured over 54 days during the summer of 2014 for two construction projects in Beijing, China. The study involved 16 rebar workers.

1. Direct Work Time: Tasks requiring specific efforts or tool usage at designated work locations that directly contribute to completing the scope of work.
2. Indirect Work Time: Support activities that do not directly contribute to the completion of specific tasks but are essential for the workflow.
3. Idle Time: Non-utilized or personal time, indicating periods of inactivity.

The data collected focused on tracking changes in outdoor heat stress and its relationship to labour productivity, enabling the development of models to quantify these impacts.

Study Parameters and Scope - Rebar workers were chosen as subjects due to the critical role they play in construction. Rebar work constitutes a significant portion of construction activity, and these workers are exposed to outdoor heat while performing routine, repetitive tasks. The consistent nature of their work methods made them ideal candidates for analysing heat-related productivity impacts. The study exclusively included male workers, as they represent the majority demographic in the construction industry.

Key Observations - The most hazardous period for workers was identified as 14:00 to 15:00, during which productivity was at its lowest.The most productive period was from 07:00 to 09:00, when workers experienced minimal heat stress.A 1^{o}C increase in outdoor temperature led to a 0.57% decrease in direct work time and a 0.74% increase in idle time.

Additional Findings - Aging was observed to have a negative impact on labour productivity, with direct work time decreasing by 0.72% for every additional year of a worker's age.Positive factors influencing productivity included work experience and Body Mass Index (BMI). An increase in work experience by one year corresponded to a 0.33% increase in direct work time.

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This study highlights the significant correlation between high temperatures and labor productivity. It emphasizes the importance of understanding environmental factors to develop strategies that optimize worker performance and safeguard health during extreme weather conditions.

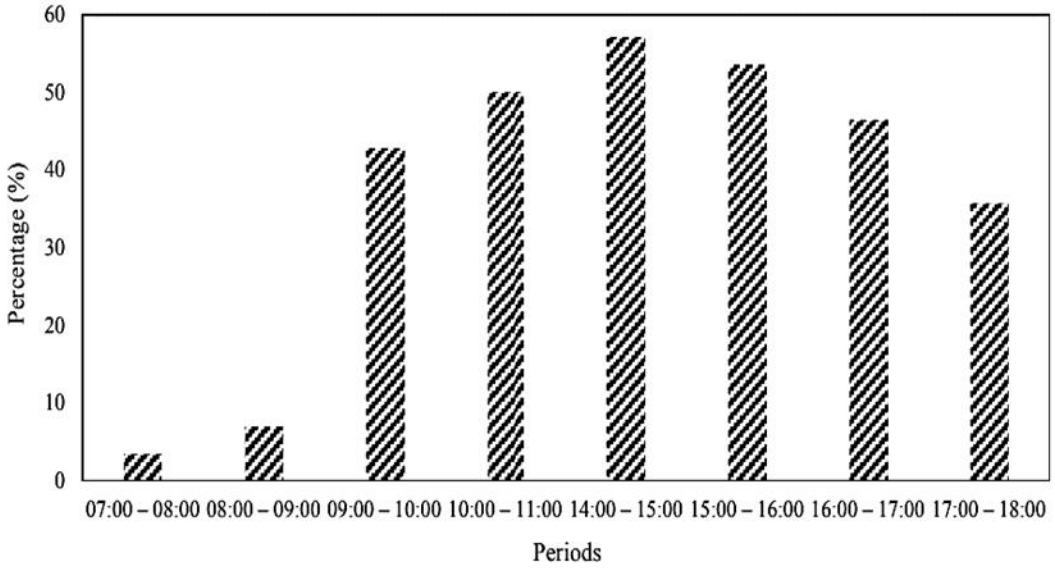

Fig.1. Hazardous time-percentage (Xiaodong et al., 2015)

IV. STATE OF ART

Table I. Analysis and mitigation strategies for extreme climate safety issues

Paper	Demographics	On-site strategies	Physical health strategies	Work-rest schedule	Automation
Karthick et al., 2020	✓				
Sanjgna et al., 2020		✓	✓	✓	✓
Ammar et al., 2021			✓		
Sanjgna et al., 2021		✓	✓	✓	

Wen et al., 2017				✓	✓
Vadim et al., 2019				✓	
Ibukun et al., 2018			✓		✓
Amin et al., 2018				✓	✓
Jianjun et al., 2013	✓		✓		

1. **Demographics**

Factors such as dehydration, worker fatigue, skin disorders, age, gender, and ethnicity significantly influence how construction workers respond to extreme weather conditions. These variables allow construction managers to make informed decisions when planning activities during periods of intense heat. Studies indicate that the impact of cold weather on respiratory function differs across genders and age groups (Karthick et al., 2020).Women's sweat rates are lower than men's, which can be disadvantageous in hot-dry environments but beneficial in hot-wet conditions due to differences in thermoregulation efficiency (Jianjun et al., 2013). Understanding these differences is key to implementing tailored interventions for workers under varying environmental challenges.

2. **On-site strategies for the prevention of climate-related injuries and illness**

To mitigate the effects of extreme weather conditions on-site, a combination of preventive strategies is essential - Hot Weather Conditions: Temporary shelters, vending machines offering cold drinks, and cooling facilities should be provided. Rotating job assignments among workers can **also** help minimize prolonged heat exposure.Cold Weather Conditions: Shelters equipped with heating mechanisms and relaxation zones should be implemented to ensure worker safety and comfort during colder months (Sanjgna et al., 2020).

Contractors should adopt eco-friendly machinery and methods that do not exacerbate on-site pollution. Encouraging prefabrication techniques can further reduce the duration of on-site work, minimizing workers' exposure to harsh environmental conditions (Sanjgna et al., 2021).For hot weather conditions, temporary shelters and vending machines with cold drinks should be provided on the site with cooling facilities, and job rotations can be implemented. Proving shelter facilities with heating mechanisms and relaxing can be done during cold weather conditions (Sanjgna et al., 2020).

3. Physical health strategies

Workers' fitness levels play a pivotal role in managing physical stress under extreme weather conditions. Key strategies to enhance physical health include - Encouraging workers to consume liquids rich in salts and electrolytes to prevent dehydration.Discouraging alcohol consumption, which exacerbates dehydration and impairs performance.Allowing self-paced work to prevent exhaustion and mitigate heat-related illnesses.

Workers exposed to high vibrations are at heightened risk of heat-induced illnesses, particularly when their heart rate surpasses the physiological threshold (Ammar et al., 2021). Providing ergonomic PPE (Personal Protective Equipment) designed for flexibility and mobility is essential to reducing worker fatigue and improving comfort (Sanjgna et al., 2021).The fitness of the workers considerably influences their physical stress. Encouraging workers to drink more liquids containing salts and electrolytes, reducing the consumption of alcohol, and allowing the workers to self-pace when exhausted should be adapted to a project (Sanjgna et al., 2020).

4. Work-rest schedules

Optimizing work-rest schedules is critical for sustaining worker productivity and well-being. Tailored schedules should include: Short morning breaks to address emotional and mental challenges. Long afternoon breaks to combat physical fatigue during the day's hottest periods (Sanjgna et al., 2021).Implementing mathematical models to design work-rest schedules can greatly enhance efficiency. These models should calculate optimal rest durations to maximize productivity while reducing fatigue. Improved scheduling also contributes to reducing overall project costs (Wen et al., 2017).

5. Automation

Adopting wearable technology enables precise data collection and real-time health monitoring of construction workers. These devices provide valuable insights into workers' physiological conditions, helping managers identify and address early signs of safety risks. Examples include - Wearable sensors for monitoring heart rate, body temperature, and hydration levels (Ibukun et al., 2018).Smart clothing equipped with InfraRed, temperature, and humidity sensors to monitor environmental conditions and worker responses (Sanjgna et al., 2020).Such innovations empower construction managers to ensure workers' safety proactively while enhancing overall project efficiency.

V. CONCLUSION

Safety hazards associated with extreme climatic conditions pose significant challenges to construction projects, and their quantification requires extensive research and data collection. Efficient planning is crucial to minimizing their impact on workers. Preventive strategies, such as providing shelters, protective equipment, and flexible work-rest schedules, are indispensable for ensuring workers' safety and well-being.

Simulation models can further support decision-making during the planning phase, helping identify optimal solutions to complete projects on time and within budget. These measures reduce safety risks and improve the reliability and performance of construction projects.

The construction industry remains committed to achieving higher safety standards through advancements in regulations and the adoption of cutting-edge technologies. The development of innovative safety performance monitoring systems, enhanced protective equipment designs, and the incorporation of BIM for 4D safety planning represent promising future trends. These initiatives will undoubtedly drive significant improvements in construction safety practices in the years to come.

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