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Promoting Employees' Well-Being to Mitigate Occupational Risks under Extreme Heat

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ABSTRACT

Heat stress poses an increasing risk to the health and safety of employees, especially in the oil and gas sector functioning in hot, arid areas like southern Algeria. This study seeks to evaluate the effects of heat stress on work behaviour and circumstances by assessing environmental data, average heat stress levels, and safety indicators from an organisational dashboard. The analysis involved a sample of 141 employees, with monthly monitoring of perceived heat stress levels using the Heat Strain Score Index (HSSI), with values fluctuating between 9 and 20 throughout 2024. The findings indicate that increased heat stress correlates with a rise in reported unsafe acts and unsafe conditions, while positive interventions diminish under prolonged harsh heat conditions. These findings underscore heat stress's detrimental impact on workers' physiology and the behavioural and organisational dynamics related to safety. The study advocates for including heat stress as a risk factor in occupational safety management systems and urges the enhancement of preventive measures, ergonomic adjustments, and continuous training, especially during extreme heat events. These findings provoke contemplation of organisational resilience against thermal hazards in high-temperature industrial settings.

1. INTRODUCTION

Heat stress constitutes a significant physical hazard in the workplace [1-5], especially in industries where employees encounter extreme temperatures, such as the oil and gas sector [6, 7]. This phenomenon is especially significant in the desert regions of the Middle East and North Africa, where extreme climatic circumstances impair body thermoregulation [8-13].

In developing countries, insufficient working conditions coupled with extended exposure to heat significantly elevate health and safety hazards for employees [14-18]. These effects may lead to heightened fatigue, diminished concentration, cognitive and physiological dysfunction, and potentially heat stroke, directly impacting productivity, well-being, and safety [1, 19-30].

The physiological and psychological responses to heat stress are contingent upon the duration and intensity of exposure, influencing factors such as body temperature, heart rate, and fluid loss [31-36], which may also promote hazardous behaviours, such as unsafe acts and conditions (UACs) [37], possibly leading to an increase in accidents [38].

The acknowledgement of heat stress as an occupational hazard originated throughout industrialisation [39]. Beginning in the 1950s, methodical study, especially within the military, facilitated a more profound comprehension of its impact on health and performance. This endeavour resulted in the formulation of guidelines by the ACGIH [40], which were later integrated into OSHA standards throughout the 1980s.

Currently, in the context of global warming, which is characterised by rising average temperatures and increased frequency of heat waves [41-43], heat stress has emerged as a significant public health and occupational safety concern. Numerous nations have fortified their laws to mitigate detrimental impacts and diminish disparities in susceptibility [41, 43].

Despite the development of various methods for assessing heat stress, their ongoing limitations warrant the implementation of approaches more suited to the realities of modern industrial settings. Conventional environmental monitoring techniques, which rely on parameters such as temperature, humidity, and wind speed, yield a generalized assessment of thermal risk, neglecting individual variations in susceptibility [30]. Numerical simulation methods, despite their complexity, necessitate substantial computational resources and extensive data sets for calibration and validation, thereby constraining their applicability in dynamic industrial environments [44].

Likewise, research utilizing ground-based sensors, although providing precise measurements, encounters limitations regarding cost, spatial, and temporal coverage, and fails to represent the heat stress experienced by employees consistently [45]. This divergence between objective measurements and subjective perceptions underscores the necessity for more cohesive, human-centered methodologies [46].

From this perspective, the application of the Heat Strain Score Index (HSSI) appears particularly relevant. This self-assessment instrument, grounded in personal thermal perception [47], possesses several advantages, including simplicity of use, non-invasiveness, and low cost [48]. The HSSI integrates the evaluation of the immediate environment, the experienced symptoms, and the employee's subjective perception to effectively identify critical levels of thermal distress and inform preventive measures in extreme climatic conditions [49, 50].

The selection of the HSSI in this study aims to transcend the constraints of traditional methods by providing a practical instrument that is tailored to individual differences and particularly applicable to the oil and gas industry. This method facilitates a more comprehensive and contextual evaluation of heat stress, integrating the subjective, physiological, and behavioural factors that influence employees' reactions to heat [51].

This research examines the effect of heat stress on occupational safety and well-being within the oil and gas industry in southern Algeria, specifically at the Sonatrach-Pertamina site in Hassi Messaoud [52]. The adopted innovative methodology integrates three complementary dimensions: quantitative environmental data from a longitudinal analysis (2021-2023), subjective evaluations utilising the HSSI, and organisational safety indicators derived from industrial dashboards.

This triangular approach enables the analysis of correlations between seasonal variations in heat stress and safety-related behaviour, particularly through the examination of Hazardous Acts and Conditions (HACs). The research's originality resides in the integration of the HSSI as a decision-making instrument within safety management systems, thereby offering a thorough characterisation of fluctuations in heat stress and their effect on occupational well-being.

This study aims to formulate empirically grounded preventive recommendations in response to climate change, where the resilience of work systems to extreme thermal conditions is becoming increasingly critical. The objective of these recommendations is to enhance both employee safety and operational efficiency in challenging climatic conditions concurrently.

2. METHODOLOGY

The questionnaire employed in this study comprises the items of the HSSI to assess perceived heat stress, serving as a standardised and validated instrument for quantifying the subjective impacts of heat in occupational settings subjected to intense thermal stress [47, 53]. along with sociodemographic information, specifically gender, age, and seniority, which was distributed to all Sonatrach-Pertamina employees during 2024. Participants were assured that their responses would be kept anonymous and that the obtained data would be utilised solely for research purposes.

Data were collected monthly, enabling the aggregation of scores into monthly averages to illustrate variations in the intensity of perceived heat stress over the seasons. The values were subsequently compared with the operational safety indicators gathered on-site through a graphical visualisation created using Python. This analysis considered three categories of behavioural data: Unsafe Acts, Unsafe Conditions, and Positive Interventions. This research aims to examine the correlations between variations in perceived heat stress and safety-related behavioural dynamics, specifically by identifying critical intervals that may elevate the likelihood of events during extreme heat conditions.

2.1 Meteorological conditions and the workforce's activities

The study is based on local meteorological data, including ambient temperatures and relative humidity, measured continuously by sensors installed on the industrial site. These data cover the entire period from 2021 to 2023, with recordings made at regular intervals to accurately characterise the thermal environment to which employees are exposed. The data was visualised and processed using the Python language. The annual temperature variations are shown in Figure 1, while the relative humidity data are illustrated in Figure 2.

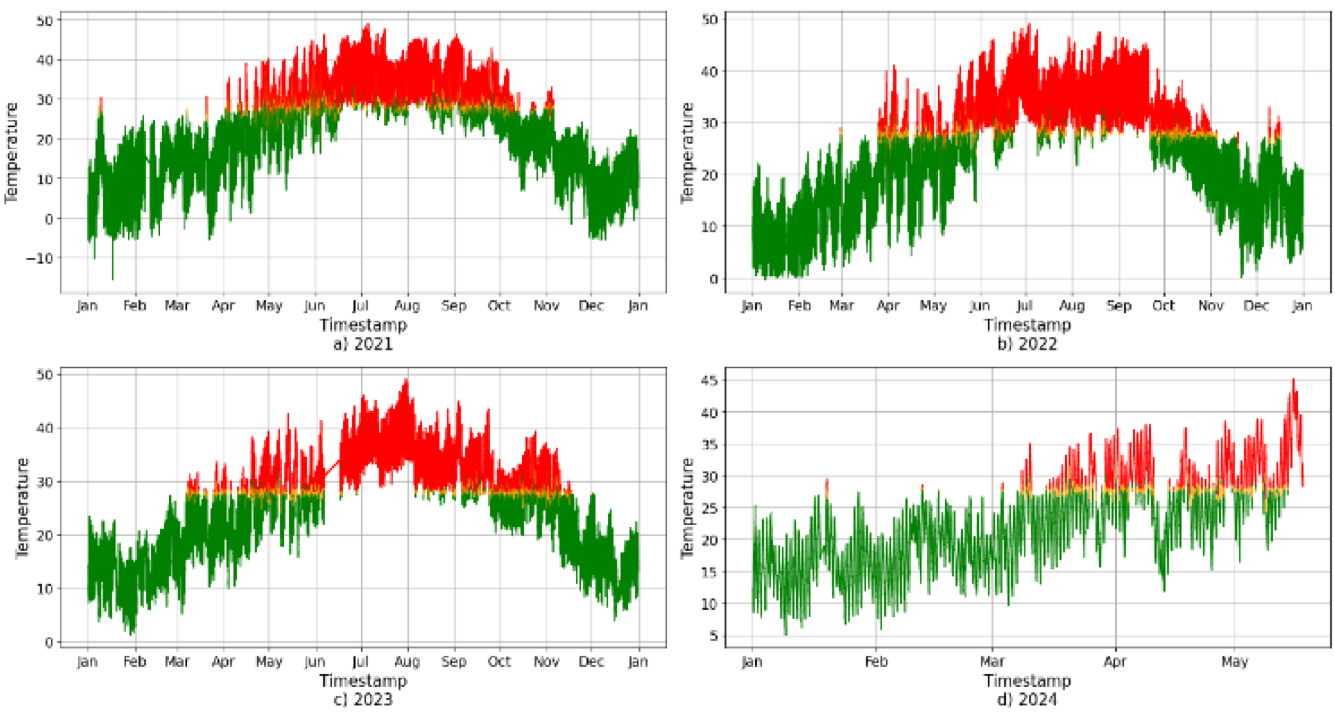

Figure 1. Temperature degrees from 2021 to 2024

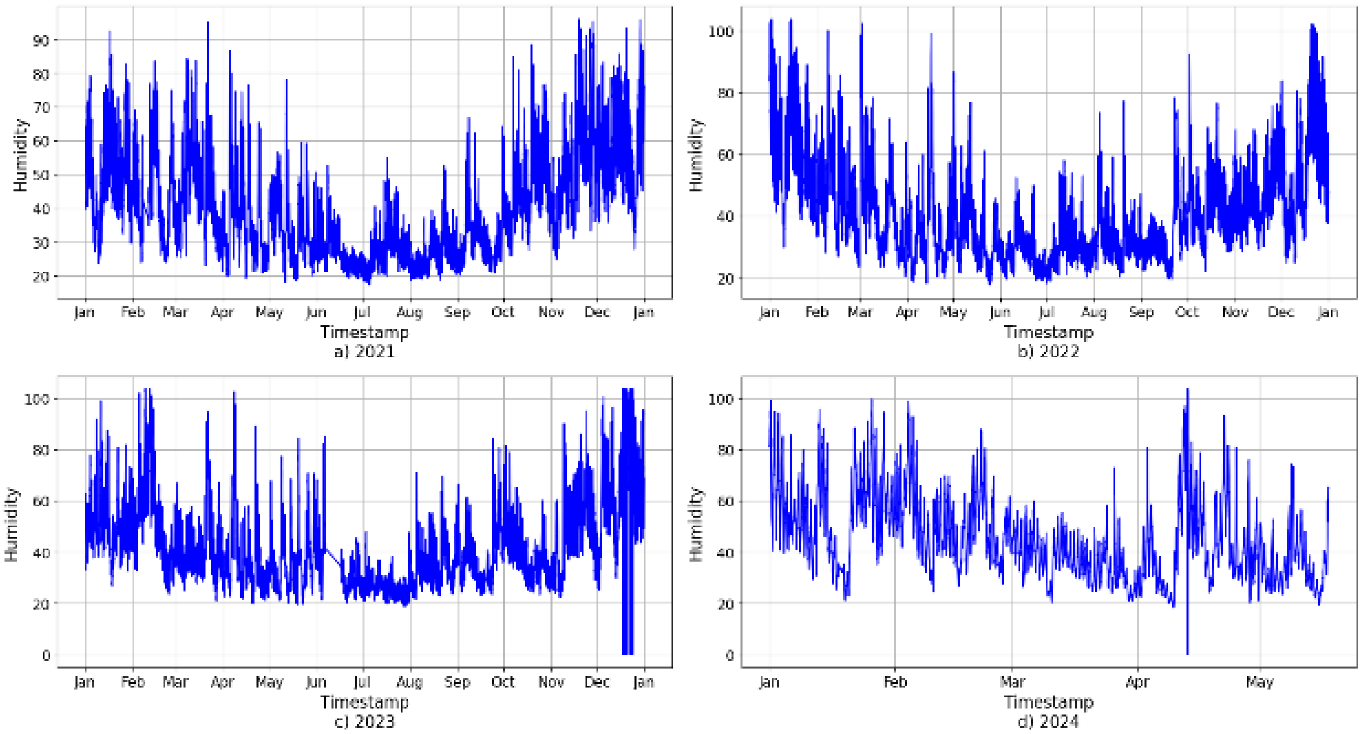

Figure 2. Humidity level from 2021 to 2024

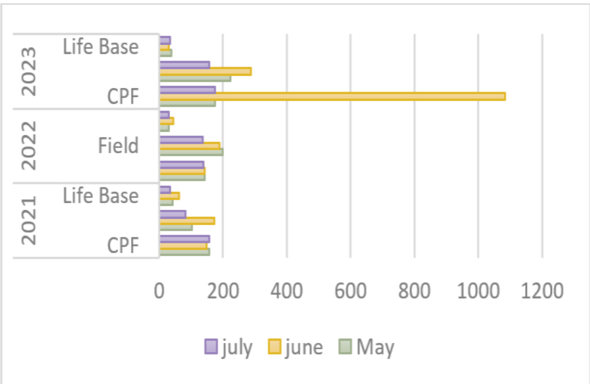

Figure 3. Number of PTW from 2021 to 2023

For the analysis, the temperatures were interpreted concerning the Threshold Limit Values (TLVs) defined for moderate to intense physical tasks, particularly: 27.5°C for high exertion and 28°C for moderate exertion [54]. Three thermal risk zones have thus been identified: a green zone for temperatures below 27.5°C, an orange zone for values between 27.5°C and 28°C, and a red zone for temperatures equal to or greater than 28°C. These classifications are illustrated in Figure 1.

The data reveal seasonal variations, with recurring heat peaks between May and July. In 2021, the maximum temperature reached 49°C, with an annual average of 33.15°C (Figure 1 (a)). In 2022, the average temperature fell slightly to 32.95°C (Figure 1 (b)), while in 2023 it rose to 33.71°C, again reaching extremes of 49°C (Figure 1 (c)).

Relative humidity, generally inversely correlated with temperature (Figure 2(a)-(d)), shows higher values in winter, with an average of 39.8% in 2021, and a marked decrease in summer, reaching only 29.15% in the hottest months. Similar trends were observed in 2022 and 2023, with summer averages of 30.35% and 31.61%, respectively.

Only data for the first few months of 2024 are currently available, covering the period up to the start of the warm season. Although only partial, these data confirm the persistence of previous trends, with temperatures already high in spring (Figure 1 (d) and Figure 2 (d)). This limitation has been taken into account in the analysis to avoid any overestimation of long-term effects.

The general climatic conditions in the region are characterised by a hot, dry climate, with maximum temperatures frequently exceeding the recommended safety thresholds for physical work. At the same time, the intensity of operational activity, as measured by the number of permits to work (PTW), has remained stable between 2021 and 2023. However, there has been a marked increase in the volume of operations during May, June, and July, which are the most critical in heat stress (Figure 3), underlining the importance of rigorous risk management during these periods.

2.2 Heat Strain Score Index

The HSSI is a tool developed to assess the perception of heat stress concerning environmental conditions in the workplace. Initially designed by Dehghan et al. [47], this index is based on a structured questionnaire designed to measure the subjective effect of heat through a set of physiological, environmental, and organisational variables.

It is particularly well suited to work environments exposed to high temperatures and humidity, but also to factors such as the intensity of physical activity, the use of protective equipment, and the symptoms experienced by employees [12, 47, 53, 55, 56].

The HSSI questionnaire comprises 18 items, each assessing a specific aspect of perceived heat stress. Unlike traditional four- or five-point Likert scales [57, 58], each response in the HSSI receives a primary score, weighted by an effect coefficient reflecting the relative importance of the variable.

The final score is obtained according to the following Eq. (1):

$$\sum_{i=1}^{18} (Primary\ score\ of\ Qi \times \text{effect coefficient of Qi}) \qquad (1)$$

The results of this assessment are classified into three levels of heat stress: a low level for a score below 13.5, a moderate or 'possible' level for scores between 13.6 and 18, and an 'ultimate' level for scores above 18 [47, 55]. This approach allows one to translate individual perceptions into quantifiable data, facilitating their integration into correlation studies with objective or behavioural indicators.

3. RESULTS AND DISCUSSION

3.1 Socio-demographic characteristics of participants

The study covered all Sonatrach-Pertamina personnel, namely 200 employees, who were administered a questionnaire ensuring their anonymity and confidentiality. A response rate of 70.5% yielded 141 useable questionnaires, which, according to the research criteria by Krejcie and Morgan [59], represents a sufficient sample size for the target group. The sample comprised solely males, and the age distribution (Figure 4) and seniority (Figure 5) indicate a predominance of employees aged 30-45, with an average seniority of 10 years, implying considerable professional experience yet varying exposure to heat stress based on the positions they held.

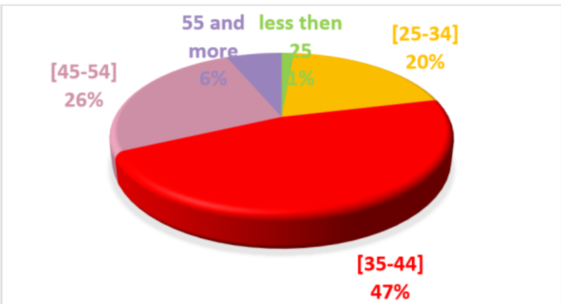

Figure 4. Distribution of employees according to age

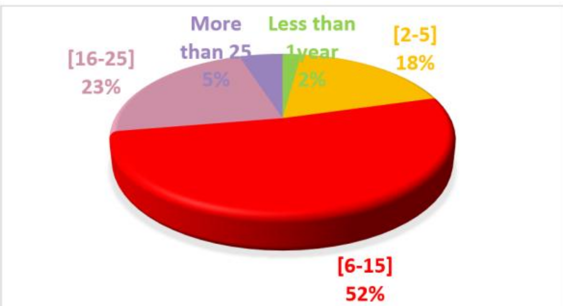

Figure 5. Distribution of employees according to seniority

3.2 Effects of heat stress on safety dynamics: Unsafe acts, unsafe conditions, and positive interventions

The monthly averages of the perceived level of heat stress AVG in 2024 show a significant variation, ranging from 10 in January to a peak of 20 in July, before gradually decreasing to 9 in December. These fluctuations can be attributed to several environmental and organizational factors, including higher outdoor temperatures during the summer months, the intensity of physical tasks performed in the field, and the mandatory use of personal protective equipment (PPE), which can disrupt body thermoregulation mechanisms. These factors combine to increase the heat load felt by employees, particularly in exposed industrial environments such as those in southern Algeria.

These fluctuations were analysed and represented graphically using the Python language. Figures 6-8 illustrate these trends by correlating them respectively with unsafe acts, unsafe conditions, and positive interventions, the leading behavioural indicators linked to safety at work.

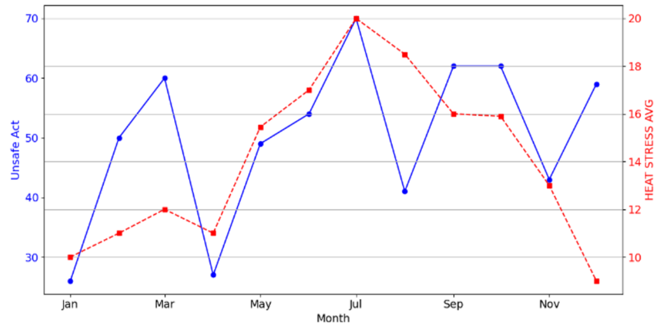

Figure 6. Monthly evolution of unsafe acts vs. heat stress AVG

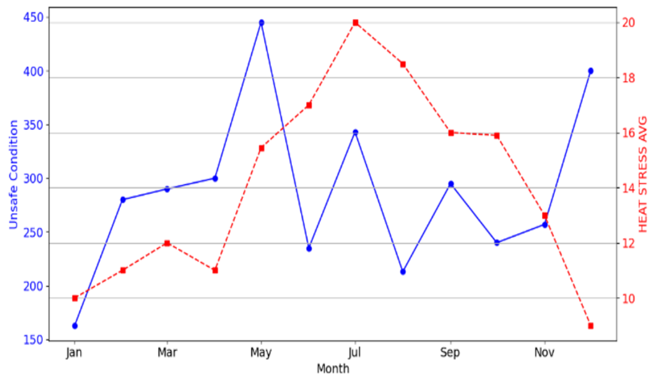

Figure 7. Monthly evolution of unsafe conditions vs. heat stress AVG

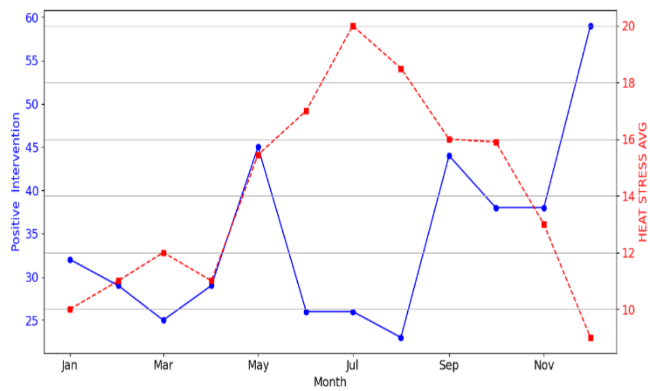

Figure 8. Monthly evolution of positive interventions vs. heat stress AVG

Figure 6 shows a proportional increase in unsafe acts as heat stress rises. These behaviours numbered 26 in January, peaked at 70 in July, a period of extreme heat.

A similar pattern is observed for unsafe conditions (Figure 7), which increased markedly between January (163 events) and May (445 events) and remained high in July (343 events), the period corresponding to the maximum level of heat stress.

In contrast, Figure 8 shows a decline in positive interventions as heat stress intensifies. The number of positive interventions, which are seen as indicators of vigilance and commitment to prevention, reaches a low in August (23 interventions) and rises to 59 in December, when temperatures become milder.

Prolonged exposure to elevated temperatures leads to an increase in core body temperature, an accelerated heart rate, dehydration, and overall fatigue, which can impair motor coordination and diminish the physical abilities necessary for safe task execution, and also impacts essential executive functions, including time perception, decision-making, risk assessment, and working memory.

These impairments may result in a decline in cognitive function, a reduction in productivity, and, in severe instances, significant accidents [60], corroborating this study's findings of a significant correlation between perceived heat stress and safety dynamics.

Therefore, it is imperative to examine the evolution of these functions under heat stress and the associated physiological mechanisms to establish guidelines for acceptable exposure durations, ensuring employees' occupational safety and well-being.

The hottest months, particularly July and August, appear to be critical periods during which operational vigilance is weakened, increasing the potential for incidents.

The significant decline in positive interventions during these periods may signify mental disengagement or cognitive overload, resulting in employees being less motivated to report risky behaviour or participate in prevention efforts.

These observations underline the need to fully integrate thermal constraints into risk management strategies, particularly in industrial environments exposed to extreme climates.

Measures such as decreasing workloads, altering schedules, enhancing ventilation, or facilitating access to rest areas can alleviate these effects and maintain essential cognitive functions for safety.

4. CONCLUSIONS

This study highlighted the significant effect of perceived heat stress, measured by the HSSI index, on occupational safety in an industrial environment. The findings suggest that heightened heat stress is associated with an increase in UACs. Simultaneously, positive interventions, vital for maintaining a proactive safety culture, often diminish during periods of elevated temperatures. The observed behavioural changes signify a shift in employees' attentiveness, anticipatory ability, and reactivity under heat stress, necessitating the development of targeted preventive strategies that incorporate heat-related risks as an essential element of health and safety performance. Proposed measures include modifying work hours to avoid temperature extremes, improving thermal comfort with appropriate equipment, promoting regular hydration breaks, and instructing teams on the early recognition of heat stress symptoms. Incorporating HSSI monitoring as a synthetic measure of perceived heat stress into safety management systems will enhance real-time operational decision-making, particularly in allocating human and material resources according to climatic conditions.

The HSSI is a validated instrument for assessing heat stress perception; however, it relies on self-assessment, rendering it significantly influenced by individual perceptions shaped by psychological, cultural, and contextual factors. This subjectivity can lead to inter-individual variations that are challenging to regulate and undermine comparability between groups, which is considered a limitation of the study. Additionally, the data were collected at a single industrial site, which limited the scope of the findings. Moreover, other organisational or psychosocial factors, not analysed in this context, may affect risk-taking behaviour, such as mental workload, time limitations, and leadership effectiveness.

To investigate these findings further, it would be essential to conduct multi-site surveys in various climatic and industrial settings, combining subjective HSSI data with objective physiological measurements (e.g., body temperature, heart rate, sweat rate). This integrated approach would not only enable us to determine critical heat tolerance thresholds objectively but also to gain a better understanding of the relationship between perception, physiological response, and cognitive performance. The adoption of longitudinal methodologies would also shed light on employees' adaptation trajectories during prolonged heat episodes, a particularly relevant aspect in the context of climate change.

This study underscores the necessity of including heat stress in occupational risk management plans comprehensively. In a world experiencing escalating heat waves, the capacity to predict and mitigate their impacts is emerging as a strategic concern, both for employee health and for organisations' sustainable efficacy.

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