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Original Article

Assessing the impact of heat stress exposure on heat strain: An analysis of outdoor and semi-outdoor roof tile workers using the Physiological Strain Index

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ABSTRACT

Introduction: This study evaluates the prevalence and contributing factors of heat strain among roof tile workers exposed to temperatures exceeding occupational limits. Furthermore, it assesses how these heat-related health risks vary between male and female workers in semi-outdoor environments.

Methods: This cross-sectional study involved 107 roof tile workers in Grobogan, Indonesia, utilizing validated questionnaires, WBGT measurements, and the Physiological Strain Index (PSI) to evaluate heat strain. Data were analyzed using Spearman's rank, Pearson correlation, and chi-square tests to identify significant relationships between individual, occupational, and behavioral factors.

Results: The PSI results of roof tile makers had an average score of 5.05 ± 0.40. The results demonstrated that female workers exhibited significantly higher physiological strain than males. This is primarily driven by biological differences in thermoregulatory capacity and greater adipose tissue insulation (p=0,000). Factors associated with heat strain were age (p=0.004), BMI (p=0.023), daily water intake (p=0.014), rest hours (p=0.000), heat stress (p=0.016), and workload (p=0.000).

Conclusion: Despite natural acclimatization keeping overall strain moderate, heat stress, physical workload, female gender, and poor hydration remain critical determinants of physiological heat strain.

Keywords: Gender, Heat Strain, Heat Stress, PSI, Roof Tile Workers

Introduction

Heat stress is the net heat load to which a worker is exposed, arising from the combined contributions of metabolic heat, environmental factors, and clothing worn, resulting in increased heat storage in the body.[1] The heat stress experienced by outdoor workers usually exceeds a WBGT of 32.1°C.[2] Exposure to heat stress is found in those who work in outdoor environments or workplaces that generate extreme heat. The roof tile industry involves industrial processes that take place in outdoor and semi-outdoor environments with exposure to heat during the production process.[3] Outdoor workers, especially in tropical and subtropical countries, may experience these conditions for several months each year.[4]

Heat stress in the roofing industry exceeds the threshold, with an average heat stress level of 37.59°C, whereas the neutral temperature range comfortably acceptable to humans is between 21°C to 26°C.[3] The human body generates heat when working and has its own thermoregulatory mechanisms. These mechanisms keep the human body cool by dissipating heat, but this is not the case for workers exposed to heat from a hot work environment.

Continuous work processes characterized by high ambient temperature and humidity, physical workloads that generate metabolic heat, and the use of inappropriate work attire combine to create heat stress hazards.[1] Consequently, the accumulation of these three factors as a heat stress load exceeding threshold limit values results in workers experiencing heat strain.[5–8] Heat strain is a physiological response to heat stress (external or internal) experienced by an individual, whereby the body attempts to increase heat release to the environment in order to maintain a stable body temperature.[1] The potential dangers of working in a hot environment depend on several physiological factors, including increased skin temperature, core body temperature, and heart rate.[9] In addition, this exposure can cause heat-related illnesses and injuries, including heatstroke, heat exhaustion, heat cramps, or heat rash, and even death.[10] Other disorders include various physiological and psychological disorders such as heat stroke, fainting, heat rash, heart failure, kidney disease, systolic heart disorders, male infertility, depression, and stress.[9,11,12]

Several studies have been conducted to identify factors contributing to the serious adverse effects of heat. Responses to heat appear to vary across populations. This is influenced by factors including age, clothing, medical history, gender, BMI, physical activity level, and body size.[13] Indeed, measuring the impact of heat exposure by monitoring physiological changes in workers exposed to heat stress exceeding threshold values is essential. Measurements are taken to prevent the body's inability to dissipate heat, which threatens workers' ability to live healthy and productive lives.[7] With the increase in extreme global temperatures, the public health burden of heat-related illnesses is expected to increase dramatically, serving as an important reminder of the importance of this research.[14–16] Therefore, the objectives of this study are to assess the incidence of heat strain in workers, the factors associated with the incidence of heat strain, and the assessment of heat strain based on gender.

Methods

This study was carried out in July 2025 by involving the entire population of roof tile workers in one of the Karangasem Village Areas, Grobogan, Central Java. The total population of roof tile workers in the village was 2,310 individuals, distributed across 20 Neighborhood Units. Due to the high homogeneity of production processes across the region, a single-stage cluster sampling was employed. One group was randomly selected as the study cluster. Within this selected group, all 115 eligible workers were invited to participate (total population sampling within the cluster). This study involved multiple production sites in 33 home industries. Inclusion comprised workers actively involved in physical production, and exclusion comprised workers unwilling to sign an informed consent form. Ultimately, 107 workers (93%) provided informed consent and were included in the final analysis, while 8 individuals declined. This study used a cross-sectional study design. The dependent variable was PSI, while the independent variables were age, work duration, years of experience, daily water intake, rest hours, and heat stress, history of illness and smoking habits, as well as BMI and workload. Written consent was obtained from all of the respondents in Indonesia. The Ethics Committee for Health Research, Faculty of Nursing and Health Sciences, University of Muhammadiyah Semarang, reviewed and approved all of the study procedures (certificate number 560/KE/07/2025).

All participants were asked to complete a questionnaire to collect information on individual characteristics, occupational factors, and behavioral characteristics, such as age, work duration, years of experience, rest hours, water consumption, history of disease, and smoking habits. BMI with height using GEA Microtoise and weight measurement using Omron HN 289 Digital Scales. Workload was measured using %CVL formula:

$$\%\boldsymbol{CVL} = \frac{\mathbf{100\ x\ (}\boldsymbol{HRwork} - \boldsymbol{HRrest}\mathbf{)}}{\boldsymbol{HRmax} - \boldsymbol{HRrest}}$$

Heat stress was measured using an Extech HT30 Heat Stress WBGT instrument. Measurements using a heat stress meter are used to measure WBGT according to ISO 7243:2017 by calculating the formula WBGT (OC) = 0.7 Tnw + 0.2 Tg + 0.1 Ta. These measurements were taken while workers were working at 1:00 PM. A total of 105 measurement points were taken, with the measurement points located close to the workers work positions, with three measurements taken each point lasting 10 minutes. The environmental conditions during the measurements included several of a home industry engaged in combustion processes during the study. The procedure for measuring heat strain involved measuring a worker's body temperature with Omron MC-720 Thermometer and pulse rate while working with Yuwell Yx301 Fingertip Pulse Oximeter. These results were then entered into the PSI (Physiological Strain Index) formula to obtain the heat strain result. Heat strain was assessed using the PSI method, which measures heart rate and body temperature.[17] PSI formula:

$$\boldsymbol{PSI} = \mathbf{5}\,\frac{(\boldsymbol{Tret} - \boldsymbol{Tro})}{(\mathbf{39,5} - \boldsymbol{Tro})} + \mathbf{5}\,\frac{(\boldsymbol{HRt} - \boldsymbol{HRo})}{(\mathbf{180} - \boldsymbol{HRo})}$$

Data analysis began with univariate analysis, where individual and job characteristic variables were presented in frequency tables with mean values ± standard deviation or median (minimum-maximum). Bivariate analysis was then performed to analyze factors related to heat strain prevalence using the Pearson correlation test and Spearman rank test for numerical data, and the chi-square test for categorical data. The Kolmogorov-Smirnov test was used to assess normality prior to the correlation test. Significance levels of $p > 0.05$ and $p \leqslant 0.05$ were used to define normality with the Pearson correlation test and non-normality with the Spearman rank test, respectively. An independent t-test was used to compare genders and PSI. All statistical tests were conducted using IBM SPSS 21 under an Academic Institutional License.

Results

As presented in Table 1, the age of roof tile workers in this study ranged from 20 to 57 years, with an average of 38 years. The workers' BMI ranged from 17.40 to 37.02 kg/m2, with an average of 27.21 kg/m2. In terms of work factors, the average working hours were 9.27 hours, with a minimum and maximum working hours of 8 hours and 13 hours, respectively. The average length of service was 8.53 years, with the longest being 20 years and the shortest being 1 year. Workers had an average of 1 hour of rest, and the workload measured by %CVL showed an average of 67.76%, with the highest workload reaching 94% in the very heavy category.

Table 1: Individual characteristics, occupational characteristics and behavioral

Variable	$\bar{x}$ ± SD	Me (Min-Max)
Age (years)	38 ± 9	39 (20 – 57)
BMI (kg/m²)	27.21 ± 0.44	27.73 (17.40 – 37.02)
Work Duration (Hours)	9.27 ± 1.44	9.00 (8.00 – 13.00)
Years of experience (Years)	8.53 ± 0.35	7.00 (1.00 – 20.00)
Rest Hours (hours)	1 ± 0.02	1.00 (0.50 – 1.50)
Workloads (%)	67.76 ± 1.08	68.50 (39.00 – 94.00)
Heat stress (°C)	37.87 ± 2.22	39.00 (32.4 – 39.7)
Heart Rate (bpm)	134 ± 7.43	134 (112 – 148)
Body Temperature (°C)	37.97 ± 0.18	37.90 (37.60 – 38.20)
PSI	5.05 ± 0.40	5.12 (4.0 – 5.9)
Water Consumption (L/days)	3.81 ± 0.12	4.00 (1.00 – 6.00)
n(%)		
History of Disease		
Yes		35 (32.7)
No		72 (67.3)
Smoking		
Yes		44 (41.1)
No		63 (58.9)

Abbreviations: BMI, Body Mass Index; PSI, Physiological Strain Index; $\bar{x}$, mean; SD, Standard Deviation; n, sample size; Me, Median; Min, Minimal; Max, Maximal; C, Celcius; L, Litre; bpm, beats per minute.

On the other hand, heat stress measurements in the working environment of roof tile makers showed an average of WBGT = 37.44°C, with the highest heat stress being 39.7°C. On the other hand, the average heart rate of roof tile makers while working was 134 bpm, with the highest being 148 bpm, and the average body temperature was 37.9°C, with the highest being 38.20°C. It is important to note that the PSI score for roof tile workers, which indicates the incidence of heat strain, showed an average of 5.05, with the highest score being 5.9. Most workers had no history of illness (67.3%), while 32.7% had a history of illness. Meanwhile, 41.1% of roof tile workers smoked, while 58.9% did not smoke. Regarding water consumption habits, roof tile workers had an average consumption of 3.81 liters (Table 1).

The body temperature data peaks sharply at two key points: 37.90 and 38.20. This is known as a bimodal distribution (having two peaks). The results of body temperature measurements of workers, grouped by gender, show that the highest temperature, 38.20°C, occurred in both women and men. In contrast to body temperature, heart rate data spread much more widely, ranging from 112.00 to 148.00. In addition, the maximum heart rate of 148 bpm was observed among male workers.

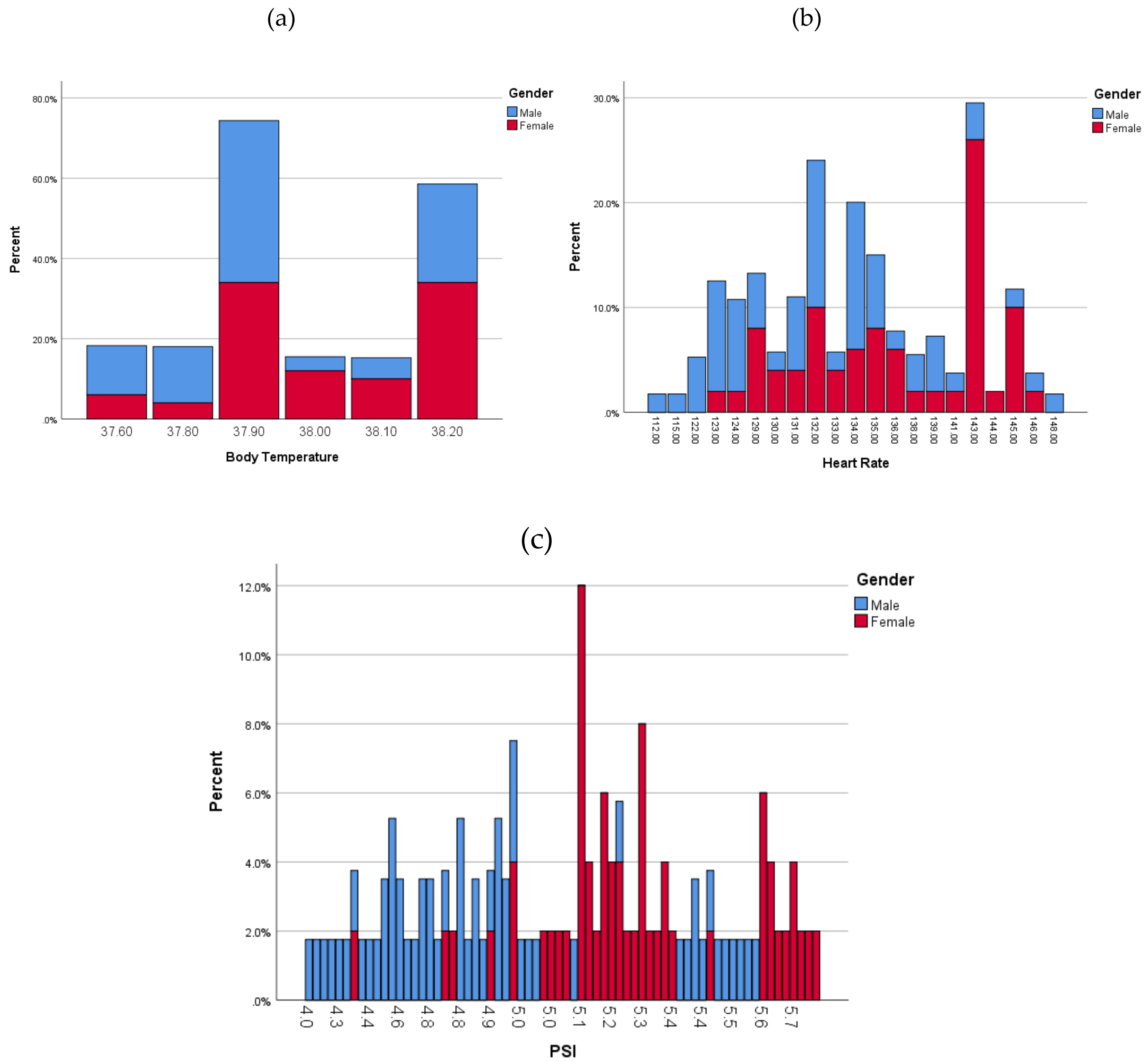

Figure 1: Results of body temperature [(a)], heart rate [(b)], and PSI [(c)] measurements based on gender grouping of roof tile workers

Table 2: Independent Test

Variable	Gender	n	Mean±SD	t	df	p-values
PSI	Male	57	4.86±0.39	-6.16	101.29	0.000
	Female	50	5.27±0.28			

Statistical test performed: Independent t-test

Female roof tile makers were the subject of research due to their low capacity to dissipate heat when exposed to heat stress.[18] This heat exposure can cause fatigue in workers.[10,19] Female workers are at greater risk of fatigue than male workers due to their smaller body size and muscle mass as a result of hormonal influences and the double burden of being a housewife,[20–22] thus, heat exposure exacerbates the condition of female workers (Table 2).

Table 3: Correlation Factors to Heat Strain among Workers

Variables	*r*	*p-value*
Age (Years)	-0.279 [b]	0.004*
BMI (kg/m^2)	0.220[b]	0.023*
Work Duration (Hours)	0.180[a]	0.064
Years of experience (Years)	0.065 [a]	0.504
Daily Water Intake (L/days)	-0.238 [b]	0.014*
Rest Hours (Hours)	-0.506[c]	<0.001*
Heat Stress (^oC)	0.232 [b]	0.016*
Workload (%)	0.334 [b]	<0.001*

*Abbreviations: BMI, Body Mass Index; PSI, Physiological Strain Index; SD, Standard Deviation; n, sample size; r, correlation coefficient. Statistical test performed: Spearman's rank test for age, work duration, years of experience, daily water intake, rest hours, and heat stress. Pearson correlation test for BMI and workload. *p<0.05. Correlation coefficient: a, very weak; b, weak; c, moderate.*

The correlation analysis results indicated that age, BMI, daily water intake, heat stress, and workload were weakly correlated with the incidence of heat strain. Meanwhile, rest hours showed a moderate correlation. Conversely, work duration and years of experience (work tenure) did not correlate with heat strain among roof tile manufacturing workers in Grobogan (Table 3).

Table 4: The Association between Smoking Habits and History of Disease with Heat Strain among Workers.

Variables	**PSI** n(%)			*p*
	All Respondents (n=107)	**Score 4.0-4.9 (n=48)**	**Score 5.0-6.0 (n=59)**	
History of Disease				
No	72 (100.0)	26 (36.1)	46 (63.9)	0.013*
Yes	35 (100.0)	22 (62.9)	13 (37.1)	
Smoking				
No	63 (100.0)	26 (41.3)	37 (58.7)	0.432
Yes	44 (100.0)	22 (50.0)	22 (50.0)	

*Statistical test performed: Chi-square test for categorical variables. *p<0.05*

Furthermore, the association test for categorical data was conducted using the Chi-square test. The results showed an association between history of disease and heat strain among heat-exposed workers, specifically roof tile manufacturing workers. In contrast, the results indicated no association between smoking habits and the incidence of heat strain (Table 4).

Discussion

This study highlights the severe heat exposure experienced by roof tile workers in Grobogan, both in outdoor and semi-outdoor environments. Outdoor working conditions occur during the initial stages of the process, when workers prepare the soil, dry the roof tiles and transport large quantities of tiles under the hot sun. Meanwhile, semi-outdoor roof tile workers refer to traditional home industry roof tile workers in Indonesia who work in huts with roofs but no walls or partially shaded walls. This condition usually apply among preparation workers, namely roof tile molders, seset workers, and burners. Several factors tested in this study explain the relationship with the occurrence of heat strain in workers exposed to this heat.

A critical contribution of this study is its empirical validation of thermal dimorphism in an occupational setting. Our findings demonstrate that women are significantly more susceptible to elevated Physiological Strain Index (PSI) than men, which aligns with, yet contextually expands upon, previous thermoregulatory studies.[23] Analytically, this heightened vulnerability is not merely a function of exposure but of inherent physiological capacities: women exhibit a higher core body temperature threshold for the onset of sweating and possess a greater percentage of adipose tissue. In the context of heavy occupational labor, this adipose tissue acts as a formidable insulator, accelerating thermal storage. Furthermore, our findings suggest that the lower baseline aerobic capacity in women exacerbates the relative cardiovascular load. When this biological predisposition is coupled with socio-cultural evaporative resistance (e.g., closed clothing), it creates a compounding effect, resulting in sharper increases in core temperature and heart rate compared to men under identical heat exposure.[23]

Age is a significant determinant of heat strain due to the progressive decline in thermoregulatory function and cardiovascular capacity associated with aging. Older workers exhibit a lower core temperature threshold and a delayed sweating response compared to their younger counterparts when exposed to extreme heat.[24] This is corroborated by findings indicating greater body heat storage and higher core temperatures in older adults compared to younger individuals.[25] Consequently, advancing age is linearly associated with increased vulnerability to heat stress-related health disorders. A high Body Mass Index (BMI) contributes to heat strain through the mechanism of thermal insulation provided by adipose tissue, which hinders the dissipation of internal body heat. Previous studies demonstrate that individuals with an above-normal BMI experience a heavier cardiovascular load and reduced evaporative cooling efficiency.[26] Furthermore, a study emphasizes that obesity increases internal metabolic heat production while simultaneously decreasing the body surface area-to-mass ratio available for heat dissipation.[5] Therefore, workers with a high BMI (obesity) face a significantly greater risk of experiencing a drastic rise in body temperature during physical exertion.

A history of chronic diseases, such as hypertension and diabetes, directly impairs physiological mechanisms for dissipating heat to the external environment via the autonomic nervous system. Patients with non-communicable diseases often experience microvascular dysfunction, which significantly limits cutaneous heat loss.[25,27] These findings are supported by previous studies explaining that certain medical conditions, as well as the side effects of their treatments, can disrupt body fluid balance and cardiac response to thermal stress.[28] In conclusion, a poor medical history serves as a risk factor that compromises a worker's tolerance threshold for occupational heat exposure. In addition, the results of this study show that there is a relationship between daily water intake and heat strain measured using the Physiological Strain Index (PSI) in critical workers. This study explains that the less water workers consume, the higher the risk of their PSI score. Insufficient fluid intake leads to a decrease in blood plasma volume, which results in an increased heart rate and an accelerated rise in core body temperature in response to physiological compensation for heat.[29] Dehydration conditions also reduce the efficiency of sweat evaporation making the body's cooling mechanism becomes less effective and increases the PSI value of.[2]

These findings are in line with a research in outdoor workers that showed that hydration status was directly related to an increase in physiological heat strain indicators, including PSI.[30] Another study reported that workers with low daily water consumption had a higher risk of developing heat strains despite working at the same level of heat stress.[31] More importantly, our findings robustly validate recent international occupational health guidelines (such as those from NIOSH or ACGIH), which emphasize that proactive, structured fluid replacement protocols, rather than relying solely on the physiological sensation of thirst, are imperative. Thus, adequate fluid intake is an important protective factor in controlling heat strain in jobs with high heat exposure, such as tile.[29] In addition to hydration factors, the results of this study show that rest hours have a meaningful relationship with heat strain in critical workers. Workers with shorter rest durations tend to experience a faster increase in the Physiological Strain Index (PSI), which reflects the body's inability to recover optimally from physiological conditions before being exposed to heat again.[32] Previous experimental research has shown that the effectiveness of physiological recovery is strongly influenced by environmental conditions during rest.[33] The study reported that recovery of core body temperature and heart rate could be optimally achieved within 15–30 minutes when workers rested at a standard effective temperature of around 18.8–24.9 °C, while recovery was slower when rest conditions were less favorable.[33] These findings reinforce the concept of occupational physiology that adequate rest time provides an opportunity for the body to lower core temperature and cardiovascular load before subsequent heat exposure.[33]

We found that the association between PSI and smoking habits, then the correlation work duration, and work experience was not affected. This is because heat strain indicates that workers' physiological responses are more influenced by other factors, such as workload and environmental factors. Workers have naturally acclimatized, and the effects of the hot environment are far more pronounced than the long-term vasoconstriction effects of nicotine. Recent physiological comparisons demonstrate that under acute heat stress, both smokers and non-smokers exhibit similar magnitudes of compensatory vasodilation, rendering baseline arterial differences statistically insignificant during peak exposure.[34] This empirical perspective aligns with the broader occupational physiology consensus: the immediate, acute severity of radiant heat and heavy physical workload dictates physiological strain far more decisively than baseline lifestyle habits. In line with this, research on outdoor workers reports that inadequate management of rest periods contributes to the accumulation of body heat and an increased risk of heat strain. Such event taking place, especially in sectors with high heat exposure and physical workloads, such as construction and manufacturing.[31] In contrast to individual and organizational factors, heat stress is the main environmental factor that is directly related to heat strain in critical workers.

This study shows that the higher the WBGT heat stress, the higher the PSI score the worker receives. The increase in environmental heat stress, which is affected by air temperature, humidity, and heat radiation, causes an increase in the external heat load received by the worker's body.[35] In response to the condition, the body increases blood flow to the skin and heart rate to maintain temperature balance, which ultimately increases the Physiological Strain Index (PSI) value.[8] Recent research shows that in hot and humid environments, the relationship between heat stress and heat strain becomes stronger due to inhibition of the sweat evaporation process.[36] In addition to exposure to environmental heat, workloads have also been shown to be related to heat strain in critical workers. Workers with higher physical workloads exhibit greater Physiological Strain Index (PSI) values, which reflect increased metabolic heat production during work activities.[37] Increased workload leads to an increase in oxygen requirements and heart rate, thereby accelerating an increase in core body temperature and physiological strain.[30,38] Previous studies have also confirmed that the combination of high workload and environmental heat stress significantly increases the risk of heat strain compared to a single exposure to each factor, making workload control a crucial aspect in preventing heat disturbances.[39]

Despite its significant findings, this study had limitations like methodological limitations. First, the cross-sectional design captures physiological and environmental data at a single point in time, restricting the ability to establish definitive causal relationships or observe dynamic physiological acclimatization over time. Second, the research was confined to a single occupational setting traditional roof tile industries in Grobogan. This specific context, characterized by unique semi-outdoor microclimates and manual workloads, limits the generalizability of the findings to other geographical regions or mechanized industrial sectors.

Furthermore, there are inherent constraints regarding environmental measurement variability. Environmental heat stress (measured via WBGT) in these settings fluctuates continuously, meaning point-in-time readings may not fully capture the cumulative thermal burden experienced by workers throughout their shifts. Finally, we encountered operational challenges typical of extreme field research, including respondent fatigue exacerbated by hot weather and heavy workloads. While mitigating the risk of nonparticipation by educating respondents about the study's occupational health benefits, maintaining absolute procedural consistency in such rigorous, uncontrolled environments remains a practical limitation.

Conclusion

Roof tile workers who work outdoors and in partially shaded environments in this study show high exposure to heat stress. This exposure result in physiological changes in the roof tile workers, as indicated by body temperature and pulse rate measurements with low and moderate PSI results. The results explain that factors not associated with heat strain incidents are length of service, working hours and smoking habits. In contrast, factors such as age, BMI, daily water intake, rest hours, heat stress, and workload are associated with heat strain. Based on gender, the highest PSI scores are observed among female workers, highlighting the need for management of physical workload and duration of heat exposure, particularly for female workers. Based on the current findings, where the Physiological Strain Index (PSI) among workers predominantly falls into the moderate category. More importantly, subsequent studies must transition from observational designs to interventional research. We strongly recommend implementing and evaluating targeted occupational heat management strategies. Future interventions should focus on engineering and administrative controls such as enforcing structured work rest cycles in climatically optimized recovery areas, establishing proactive hydration protocols, and applying localized shading to prevent this moderate physiological strain from escalating into severe, acute heat-related illnesses.

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