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Assessment of Occupational Heat Exposure among Power Plant Workers in the Context of Climate Change

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ABSTRACT

Heat stress in power plant operations is considered a serious threat to the health and safety of workers. This study aimed to perform a heat stress assessment using the WBGT index among power plant workers in the context of climate change. The study was conducted at 23 operating locations and involved workers engaged in the electricity production process at a power plant in Rayong Province, Thailand. The study's instruments included a Wet Bulb Globe Temperature (WBGT) monitor and a heat stress assessment tool. The heat index was calculated to evaluate the impact of heat exposure in the study area. The results of this study showed that the WBGT values during work ranged from 22.7°C to 32.5°C. The relative humidity ranges from 67% to 70%. The metabolic rate of 198.5 kilocalories per hour is categorized as a light workload. This is compared to the standard values established by the American Conference of Governmental Industrial Hygienists (ACGIH) Threshold Limit Values (TLVs) for heat stress. Most of the values are within the specified range. Assessing the potential hazards of heat exposure using heat index measures requires extreme caution, as sunstroke, heat cramps, and heat exhaustion can occur after prolonged exposure to the sun during physical activities. Climate change significantly impacts human health by increasing the prevalence of heat-related illnesses, respiratory conditions, and the spread of infectious diseases, ultimately straining healthcare systems and threatening public well-being.

Keyword: Assessment, Climate Change, Heat Exposure, Occupational Health, Power Plant

1. INTRODUCTION

Heat is a significant and common health risk for individuals working in a wide variety of environments, both indoors and outdoors. The combination of heat exposure from the work environment and heat generated by metabolic processes can lead to an increase in body temperature. [1][2][4][53]. Heat stress is a significant factor for individuals who work in high-temperature environments for extended periods. Heat stress, particularly in outdoor workplaces in hot, dry regions, can affect physical and mental function, impairing human performance. The assessment of occupational heat stress must be conducted

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using internationally recognized indices. [3][5][6]. The Wet-Bulb Globe Temperature (WBGT) index, approved by the International Organization for Standardization (ISO), is one of the most well-known and frequently used indices for estimating heat stress among workers in hot environments. This index takes into account the effects of basic parameters in any human thermal environment. [9][10][11]. Currently, climate change is having serious impacts on the safety and health of workers worldwide. Workers are among those most exposed to climate change hazards, yet they often have no choice but to continue working, even when conditions are dangerous. According to the latest estimates, over 2.4 billion workers are exposed to excessive heat at work each year, and around 1.6 billion workers are exposed to solar UV radiation. Air pollution is also a concern for billions of workers, particularly those working outdoors. Hundreds of thousands of workers are dying from hazardous exposures aggravated by climate change. Extreme weather events are increasing, exposing workers to wildfires, flooding, and major industrial accidents. [8][13][16][22]. This aims to reduce workers' health hazards and monitor body heat to ensure it does not exceed safe levels, according to the American Conference of Governmental Industrial Hygienists (ACGIH). [7][42]. It has been found that body heat from work should not cause the body temperature to rise above 38°C for those who are sensitive to heat, or above 38.5°C for those who are accustomed to heat. Otherwise, severe symptoms may appear, such as fatigue, vomiting, dizziness, lightheadedness, fainting, and a rapid heartbeat. [12][15][17].

In Thailand, the Department of Labor Protection and Welfare issued an announcement regarding the temperature in workplaces. The Ministry of Labor requires the measurement of Wet Bulb Globe Temperature (WBGT) during the hottest month of the year, as well as during the two hottest hours of the day. [38][39][44]. The organizations required to conduct measurements are as follows, organizations that use heat sources or perform work that may expose employees to heat. Employers are required to prepare and provide personal protective equipment as necessary and conduct health checks for employees accordingly. [11][25]. Climate change in Thailand impacts outdoor workers by increasing the risk of heat stress, dehydration, and heat-related illnesses due to rising temperatures and more frequent heatwaves. Workers in industries such as agriculture, construction, and transportation are particularly vulnerable to these conditions. The intensified heat and prolonged exposure to high temperatures can also lead to reduced productivity and increased health risks, including fatigue, sunstroke, and long-term conditions like skin cancer. These challenges necessitate effective heat stress management strategies, such as adjusting work hours and providing personal protective equipment [44].

A combined cycle power plant in Rayong Province, Thailand. There are two systems involved a type of power plant that combines a gas turbine and a steam turbine to generate electricity. The gas turbine is used to generate electricity directly, and the exhaust gases from the gas turbine are used to generate steam in a heat recovery steam generator (HRSG). The produced steam is then used to drive a steam turbine, which also generates electricity [40]. Furthermore, electricity is produced continuously throughout the 24 working hours. Through the observation of individuals involved in the electricity generating process, it was found that employees' work must be inspected during the production process in each location [47]. Some places have high temperatures

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leading to the heat in the workplace could risk workers. This power plant has established safety procedures, but it's insufficiently thorough or efficient.

Therefore, this study aimed to assess heat stress using the WBGT index among power plant workers in the context of climate change in Rayong Province, Thailand. The information gathered will be used to provide comprehensive guidelines to improve the efficiency of prevention and control measures for potential risks and hazards affecting workers in power plants.

2. MATERIALS AND METHODS

2.1 Plant and Process Description

This is a cross-sectional study conducted in a power plant located in Rayong province, Thailand. The data collection was conducted throughout the months of April to May in the year 2024. The investigation was conducted in an environment with continuously high ambient temperatures ranging from 37-38 degree Celsius for around 3-4 months each year. The standard daily working hours for employees are 8 hours. However, during periods of high production, some workers may be required to work an additional 1-2 hours of overtime on random days.

2.2 Methodology

A total of twenty-three stations throughout the power plant were chosen as locations where workers could potentially be exposed to heat stress. The heat measurements were taken using guidelines specified by the National Institute for Occupational Safety and Health (NIOSH) [55].

2.3 Tools and Equipment

The research is using the Heat Stress Wet Bulb Globe Temperature (WBGT) Meter model EXTECH HT200 as its primary tool. The measurement process complies to the ISO7243 requirements. Effectively completed the calibration process for the measurement instruments. Perform the calibration procedure to ensure the precision of the device on January 18, 2024. This is an immediate evaluation of the WBGT index. It is enough to take one measurement at a height of 1.1 meters above the ground, where the heat stress is highest. The equipment will be positioned in close proximity to the eat source [55], as shown in Figure 1.

Figure 1. Heat Stress Monitor WBGT [19]

2.4 Heat Stress Exposure Measurement

The WBGT-TWA values are measured and calculated using the 3M/ QuesTemp32 heat stress monitor, with the serial number TPQ030024.The accuracy of the instrument is calibrated according to the DIN EN 27243 standard on January18, 2024. The WBGT test should be conducted for a two-hour period that aligns with the highest level of heat stress, known as the peak heat stress. Specifically, this occurs during the daytime or when the heat-generating equipment is being used [38][39].

Additionally, the measurement period is scheduled to occur at regular intervals of five minutes, resulting in a total of 23 samples within one hour in certain locations. The measuring point should be situated at the precise location where personnel carry out their tasks, totalling twenty-three points in total.

The standard methods allow WBGT calculation inside and outside buildings, even without solar radiation data, using

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these variables in equations 1 and 2 [38][39][55].

For indoor and outdoor conditions with no solar load,

$$WBGT_{in} = 0.7T_{nw} + 0.3\,T_g \quad (1)$$

The formula is modified for measurement of the environments of the environment outside buildings with solar radiation:

For outdoors with a solar load,

$$WBGT_{out} = 0.7T_{nw} + 0.2\,T_g + 0.1T_{db} \quad (2)$$

T_{nw} is the natural wet bulb temperature (measured with a wet wick thermometer exposed to the local air movement and radiation).

T_g is the temperature in the centre of a 150 mm diameter black globe.

T_{db} is dry bulb temperature refers basically to the ambient air temperature measured by a thermal sensor, such as ordinary mercury in glass thermometer, that is shielded from direct radiant energy sources.

Although wind speed is not directly measured and included in the above equation, T_{nw} and T_g combine the effects of radiation, humidity, air temperature and wind.

To determine the average Wet Bulb Globe Temperature (WBGT) according to the ISO 7243 standard, Ministerial Regulations: The standard of management and operation on Safety, occupation, and workplace environment regarding to heat, light and noise, B.E.2559 (A.D.2016) [58]. and Notification of Department of Labor Protection and Welfare prescribing Measurement, Analysis Method and Regulated Business Type related to Heat, Lighting and Noise in Workplace, B.E.2561 (A.D.2018) [38]. The time weighted average WBGT is given by the following formula as shown in equation 3.

$$WBGT_{TWA} = (WBGT1\times T1) + (WBGT2\times T2) + \ldots + (WBGTn \times Tn))/ (T1+T2+\ldots+Tn) \quad (3)$$

where:
WBGT1 is WBGT (ºC) in T1 (min.)
WBGT2 is WBGT (ºC) in T2 (min.)
WBGTn is WBGT (ºC) in Tn (min.)
T1+T2+……+Tn = 120 mins at WBGT Max.

2.5 Heat Stress Assessment

2.5.1 Workload Assessment

Under conditions of high temperature and heavy workload should determine the work-load category of each job as shown in equation 4 and the assessment of work as shown in Table 1. [7][57].

Cool rest area: When heat conditions in the rest area differ from those in the work area, the metabolic rate (M) should be calculated using a time-weighted average.

$$Average_M = \frac{(M1)(t1)+(M2)(t2)+\ldots+(Mn)(tn)}{(t1)+(t2)+\ldots+(tn)} \quad (4)$$

where:
M = metabolic rate
t = time in minutes

Table 1. Assessment of Work

Body position and movement	kcal/min*	
Sitting	0.3	
Standing	0.6	
Walking	2.0-3.0	
Walking uphill	Add 0.8 for every meter (yard) rise	
Type of work	**Average kcal/min**	**Range kcal/min**
Hard work		
Light	0.4	0.2 – 1.2
Heavy	0.9	
Work: One arm		
Light	1.0	0.7 – 2.5
Heavy	1.7	

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Work: Both arms		
Light	1.5	1.0 – 3.5
Heavy	2.5	
Work: Whole Body		
Light	3.5	2.5 – 15.0
Moderate	5.0	
Heavy	7.0	
Very Heavy	9.0	

*For a standard worker of 70 kg body weight and 1.8 m2 body surface. ACGIH

2.5.2 Metabolic Rate

The metabolic rate is impacted by the employees' job responsibilities and the period they are exposed to heat during work. Refer to Table 2 for instructions on how to choose the appropriate work rate category

.

Table 2. Metabolic Rate Categories and Example Activities

Workload	Metabolic Rate [W][a]	Thai Regulation (kCal/hr)[b]	Examples
Rest	115	-	Sitting
Light	180	<200	Sitting with light manual work with hands or hands and arms and driving. Standing with some light arm work and occasional walking.
Moderate	300	201-350	Sustained moderate hand and arm work, moderate arm and leg work, moderate arm and trunk work, or light pushing and pulling. Normal walking. Moderate lifting.
Heavy	415	>350	Intense arm and trunk work, carrying, shovelings, manual sawing, pushing, and pulling heavy loads, and walking at a fast pace. Heavy materials handling.
Very Heavy	520	-	Very intense activity at fast to maximum pace.

[a] Metabolic rate from TLVs and BEIs by ACGIH 2015 [56]. The effect of body weight on the estimated metabolic rate can be accounted for by multiplying the estimated metabolic rate by the ratio of actual body weight divided by 70 kg (154 lb).
[b] Ministry of Labor of Thailand. Ministerial Regulation on the Prescribing of Standard for Administration and Management of Occupational Safety, Health, and Environment in Relation to Heat, Light, and Noise B.E.2559 (A.D.2016) [36].

2.6 Heat Index

The heat index is a measure that considers the combined impact of heat and humidity to determine the perceived temperature. Direct sunlight raises the heat index by 15°F, which can be utilized to estimate when outdoor activities should be avoided and the resulting health effects, as shown in Figure 2 and Table 3 [41][43].

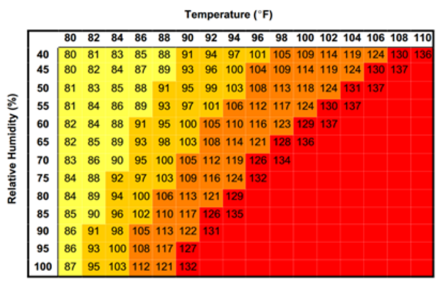

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Table 3. Effect of the heat index

Classification	Heat Index (ºC)	Heat Index (ºF)	Possible heat disorders
Extreme Danger	Over 54	Over 130	Heat stroke/sunstroke highly likely with continued exposure
Danger	41-54	105-130	Sunstroke, heat cramps, or heat exhaustion likely, and heatstroke possible with prolonged exposure and/or physical activity.
Extreme Caution	33-40	90-105	Sunstroke, heat cramps, and heat exhaustion possible with prolonged exposure and/or physical activity.
Caution	27-32	80-90	Fatigue possible with prolonged exposure and/or physical activity.
Safe	<26	<80	No adverse effects expected due to heat

2.7 Factors of Clothing

Clothing provides an insulation that reduces or prevents the transfer of heat between the skin and the surrounding environment, providing thermal resistance. It is important to conduct a heat stress assessment, as it determines the rate at which sweat can evaporate from the skin and cool the body. gaps, flaps, and openings in clothing, as well as air permeability, can alleviate heat stress by directly transferring hot, moist air from the skin to the environment [57]. The ACGIH has classified the modification of clothing using the requirements [7] shown in Table 4.

Table 4. Clothing Adjustment Factors for some clothing ensembles

Clothing Type	Addition to WBGT (ºC)
Work clothes (long sleeve shirt and pants)	0
Cloth (woven material) coveralls	0
Double-layer woven clothing	3
SMS polypropylene coveralls	0.5
Polyolefin coveralls	1
Limited-use vapor-barrier coveralls	11

3. RESULTS AND DISCUSSION

3.1 Characteristics of the subjects

A total of 23 work areas were discovered in the power plant through field observations and onsite discussions with power plant workers. These activities were carried out continuously in sunny weather, every day of the week. The workday normally started between 07:00 a.m. and 07:00 p.m., depending on the arrival time at the site. However, it was found that the activities of power

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plant workers, both inside or outside, were limited to a maximum of 3-4 hours per day. Normally, all employees comply to a uniform dress code which consists of long-sleeved shirts, long trousers, safety footwear, protective helmets, and safety gloves when on responsibility. The results of this study were consistent with several prior studies that climate change and occupational heat stress in outdoor workers are likely to cause dehydration, fatigue, dizziness, disorientation, decreased brain function, loss of attention, and pain [18][20][21][37].

3.2 Heat Stress Measurement and Assessment

The heat levels associated with the electricity production process area were measured at 23 work areas. The average maximum wet bulb globe temperature (WBGT) measurement value was determined to be 32.5 degrees Celsius, while the average minimum WBGT measurement value was 22.7 degrees Celsius, respectively. The comparison is conducted using safety guidelines as specified in the ministerial regulations that set the standards for managing and operating safety in heat-related work. According to the findings of Light and Sound 2016, the temperature in the work area was not going over the specified limit of 34 degrees Celsius. However, when compared to ACGIH's standard criteria, it was discovered that the temperature exceeded the standard at all 7 sites, as shown in Table 5.

The results of this study were consistent with several prior studies that WBGT index is rising. The explanation for this increase could be global warming or a lack of suitable work conditions in these areas. It would be a warning for workers who are working in outdoor environments or hot operating conditions [27-30]. Therefore, regarding the adverse effects of the heat on workers' health and impose additional expenses on workers, it is important to evaluate the working conditions of them [49][50].

Table 5. The result of heat stress measurement

No.	Work Location	Duration Measured (mins)	Weather Condition	Measurement Data					Standard Exposure limit TLV & AL (ºC)		Evaluation Compliance	
				T_{NWB}	T_{GT}	T_{DB}	$WBGT_{in/out}$ (ºC)	$WBGT_{TWA}$ (ºC)	(1)	(2)	(1)	(2)
1	Location No.1	120	Sunny	28.2	37.8	33.7	31.1 (in)	31.1	34.0	31.0	Pass	Not Pass
2	Location No.2	120	Sunny	28.9	37.2	33.9	31.0 (out)	31.0	34.0	31.0	Pass	Pass
3	Location No.3	120	Sunny	28.1	35.3	34.9	30.3 (in)	30.3	34.0	31.0	Pass	Pass
4	Location No.4	120	Sunny	27.9	35.2	33.3	30.0 (in)	30.0	34.0	31.0	Pass	Pass
5	Location No.5	120	Sunny	28.2	37.7	32.1	30.4 (out)	30.4	34.0	31.0	Pass	Pass
6	Location No.6	120	Sunny	28.9	41.6	33.4	31.9 (out)	31.9	34.0	31.0	Pass	Not Pass
7	Location No.7	120	Sunny	27.8	38.8	33.4	30.6 (out)	30.6	34.0	31.0	Pass	Pass
8	Location No.8	120	Sunny	28.6	35.6	34.2	30.5 (out)	30.5	34.0	31.0	Pass	Pass
9	Location No.9	120	Sunny	29.0	36.8	35.0	31.2 (out)	31.2	34.0	31.0	Pass	Not Pass
10	Location No.10	120	Sunny	28.3	32.4	32.2	29.5 (in)	29.5	34.0	31.0	Pass	Pass
11	Location No.11	120	Sunny	20.7	27.4	27.1	22.7 (in)	22.7	34.0	31.0	Pass	Pass
12	Location No.12	120	Sunny	22.0	27.2	26.8	23.6 (in)	23.6	34.0	31.0	Pass	Pass
13	Location No.13	120	Sunny	28.3	37.6	33.8	30.7 (out)	30.7	34.0	31.0	Pass	Pass
14	Location No.14	120	Sunny	30.1	38.3	37.9	32.5 (in)	32.5	34.0	31.0	Pass	Not Pass
15	Location No.15	120	Sunny	28.3	37.2	33.8	30.9 (in)	30.9	34.0	31.0	Pass	Pass
16	Location No.16	120	Sunny	28.7	38.6	34.9	31.3 (out)	31.3	34.0	31.0	Pass	Not Pass
17	Location No.17	120	Sunny	28.1	35.5	35.0	30.3 (in)	30.3	34.0	31.0	Pass	Pass
18	Location No.18	120	Sunny	28.0	40.2	32.7	30.9 (out)	30.9	34.0	31.0	Pass	Pass

19	Location No.19	120	Sunny	27.9	37.6	34.7	30.5 (out)	30.5	34.0	31.0	Pass	Pass
20	Location No.20	120	Sunny	28.1	40.5	32.8	31.0 (out)	31.0	34.0	31.0	Pass	Not Pass
21	Location No.21	120	Sunny	27.9	35.1	32.7	29.8 (out)	29.8	34.0	31.0	Pass	Pass
22	Location No.22	120	Sunny	30.0	38.0	37.5	32.4 (in)	32.4	34.0	31.0	Pass	Not Pass
23	Location No.23	120	Sunny	28.3	34.9	33.8	30.2 (out)	30.2	34.0	31.0	Pass	Pass

[1] Regulation of The Ministry of Labour B.E.2559 (A.D.2016)
[2] American Conference of Governmental Industrial Hygienists (ACGIH), 2017

3.3 Heat Exposure

Through the observation and documentation of employees' work postures during the electricity production process, specific work characteristics were identified. These include driving from the office to the work area, growing stairs, inspecting machines, recording information, and preparing computer documents. This activity has a metabolic rate of 198.5 kilocalories per hour, which is classified as a light workload. Heat exposure is a major cause of health issues in outdoor workers. Therefore, there is a need for implementing control measures and continuous actions such as environmental and physiological monitoring, light clothing, and flexible work shifts [45][46][48].

The measurement of the Heat Index (HI) for the 23 work areas in this study. The result found that a total of 21 places were identified to have a Heat Index (HI) falling into an "Extreme caution" category, indicating that extended exposure and physical exertion could potentially result in sunstroke, heat cramps, and heat exhaustion. UV radiation causes short-term injuries such as sunburn, skin blistering, and eye damage, but the long-term impacts can be severe. The International Agency for Research on Cancer (IARC) has classified solar radiation and its various components, specifically UVA, UVB, and UVC, as carcinogenic to humans [22,31-35]. Nevertheless, the likelihood of power plant personnel being impacted by this intense heat is likely to be low because most workers do their duties indoors and have limited exposure to outdoor tasks, as seen in Table 6.

In addition to the environmental heat that is imposed on the workers, these individuals are at a high risk of heat stress due to the high metabolic heat load that occurs during their shifts. This work involves intense arm and trunk work, as well as the carrying, pushing, and pulling of heavy loads [23][24][26]. As a result, the organization includes heat-related hazards as a key priority in Occupational Safety and Health policies and strategies, recognizing the importance of protecting workers and workplaces in general from this growing risk, and defining assesses and initiatives to be implemented [51][52][54].

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Table 6. The result of heat index assessment

No	Work Location	Time Measurement	Relative Humidity (%)	Heat Index (ºC)	Heat Index (ºF)	Clothing Adjustment Factor	Work Load	Metabolism Rate (kcal/hr) [a]	Risk Decision
1	Location No.1	09:30-11:30	70	37.9	100.2	None	Light	198.5	Extreme Caution
2	Location No.2	09:30-11:30	70	37.6	99.7	None	Light	198.5	Extreme Caution
3	Location No.3	09:30-11:30	70	35.8	96.4	None	Light	198.5	Extreme Caution
4	Location No.4	09:30-11:30	70	35.1	95.1	None	Light	198.5	Extreme Caution
5	Location No.5	13:00-15:00	67	36.1	96.9	None	Light	198.5	Extreme Caution
6	Location No.6	13:00-15:00	67	39.1	102.3	None	Light	198.5	Extreme Caution
7	Location No.7	13:00-15:00	67	35.8	96.3	None	Light	198.5	Extreme Caution
8	Location No.8	09:30-11:30	70	36.3	97.3	None	Light	198.5	Extreme Caution
9	Location No.9	09:30-11:30	70	38.2	100.7	None	Light	198.5	Extreme Caution
10	Location No.10	09:30-11:30	70	33.9	92.9	None	Light	198.5	Extreme Caution
11	Location No.11	09:30-11:30	70	22.9	73.1	None	Light	198.5	Safe
12	Location No.12	09:30-11:30	70	23.9	74.9	None	Light	198.5	Safe
13	Location No.13	12:30-14:30	67	36.0	96.8	None	Light	198.5	Extreme Caution
14	Location No.14	12:30-14:30	67	40.8	105.3	None	Light	198.5	Extreme Caution
15	Location No.15	09:30-11:30	70	37.4	99.2	None	Light	198.5	Extreme Caution
16	Location No.16	09:30-11:30	70	38.4	101.1	None	Light	198.5	Extreme Caution
17	Location No.17	09:30-11:30	70	35.8	96.4	None	Light	198.5	Extreme Caution
18	Location No.18	13:00-15:00	67	36.5	97.6	None	Light	198.5	Extreme Caution
19	Location No.19	13:00-15:00	67	35.5	95.9	None	Light	198.5	Extreme Caution
20	Location No.20	13:00-15:00	67	36.7	98.1	None	Light	198.5	Extreme Caution
21	Location No.21	13:00-15:00	67	33.9	93.0	None	Light	198.5	Extreme Caution
22	Location No.22	12:30-14:30	67	40.5	104.8	None	Light	198.5	Extreme Caution
23	Location No.23	12:30-14:30	67	34.8	94.6	None	Light	198.5	Extreme Caution

[a] Ministry of Labor of Thailand. Ministerial Regulation on the Prescribing of Standard for Administration and Management of Occupational Safety, Health, and Environment in Relation to Heat, Light, and Noise B.E.2559 (A.D.2016).

4. CONCLUSIONS

Based on the findings of this study, it can be inferred that power plant workers working in the electricity production process of a power plant in Rayong Province, Thailand. Exposure to heat is a potential hazard. The following risk factors have been identified. The metabolic rate of workers is 198.5 kilocalories per hour. It is defined as a light workload. The working environment has a temperature range of 22.7–32.5 ºC which is within the normal range of temperatures, not exceeding 34 ºC. The Heat Index is calculated at the given level of extreme caution temperature. This might raise the chance of more damage from heat exposure through related problems such as, sunstroke, heat cramps, and heat exhaustion possible with prolonged exposure and physical activity respectively.

The effects of climate change and excessive heat on human health, effects of occupational heat exposure. The consequences include extreme fatigue, copious perspiration, and an immediate inability to resume work. There were illnesses among power plant workers who work in outdoor areas, which can lead to health effects such as sweating, thirst, itchy rashes, fatigue, exhaustion, dizziness, headaches, muscle cramps, vomiting, and weakness.

The value of research in the occupational heat exposure assessment is recommended. Firstly, Engineering controls aim to decrease workers' activity by implementing mechanical aids, enclosing or insulating hot surfaces, ensuring sufficient ventilation, and reducing humidity when necessary. Additionally, administrative controls involve overseeing workers, implementing work-rest schedules, and establishing emergency procedures. Lastly, there are certain types of personal protective equipment available, such a cool vest, luminous suit, and heat transfer suit.

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