

INTEGRATING TEMPERATURE, HUMIDITY, PRESSURE, AND WBGT FOR OCCUPATIONAL HEAT RISK MONITORING

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Temperature:
31°C

Humidity:
65%

Solar Radiation:
950 W/m²



EXECUTIVE SUMMARY

Occupational heat exposure is emerging as one of the most significant environmental safety challenges affecting workers and athletes across climate-exposed operational environments. Rising global temperatures and increasing frequency of heatwaves are intensifying physiological strain across sectors, including mining, construction, utilities, logistics, and sports training infrastructure.

Traditional monitoring approaches relying solely on ambient air temperature are insufficient to represent real exposure conditions, as they fail to account for the full range of environmental influences on human heat stress. Human heat stress depends on multiple environmental factors, including humidity, radiant heat exposure, and airflow conditions, making it necessary to use a more comprehensive assessment approach. Wet Bulb Globe Temperature (WBGT) is internationally recognized as the preferred environmental screening index for assessing occupational heat exposure because it integrates these variables into a single, actionable indicator.

Modern environmental monitoring platforms equipped with global temperature sensing capabilities enable continuous WBGT estimation across distributed operational environments, supporting safer workforce planning and alignment with international occupational safety guidance frameworks.

Integrated monitoring infrastructure is increasingly becoming a foundational component of climate-resilient workplace safety strategy and the backbone of modern heat stress monitoring systems and industrial heat stress management programs.

INTRODUCTION

EHS and safety professionals working in climate-exposed environments are increasingly recognizing occupational heat exposure as a significant safety concern. Increasing heat stress due to higher temperatures and complex environmental conditions is exacerbating the limitations of traditional temperature-monitoring methods in accurately representing real-world exposure.

This paper describes a comprehensive framework for assessing heat exposure risk by integrating the primary environmental factors that influence it; it highlights how composite indices such as WBGT enable objective, standardized evaluation. It also examines how new monitoring technologies provide real-time, data-driven decision-making tools for effective management of heat stress across industrial and infrastructure sectors.

THE RISING CHALLENGE OF OCCUPATIONAL HEAT STRESS

Heat stress occurs when the body's ability to dissipate metabolic heat becomes insufficient under environmental exposure conditions. This leads to elevated core body temperature and increased risk of fatigue, dehydration, cognitive impairment, and heat illness. This makes environmental heat exposure monitoring a critical requirement for ensuring worker safety and operational continuity.

According to the International Labour Organization, approximately 2.2% of global working hours are expected to be lost annually due to occupational heat exposure by 2030.

Heat exposure risk is increasing due to:



Rising Global Temperatures



Growth In Outdoor Infrastructure



High-Intensity Workloads



Urban Heat Island Effects



Surface Radiation In Sports Environments

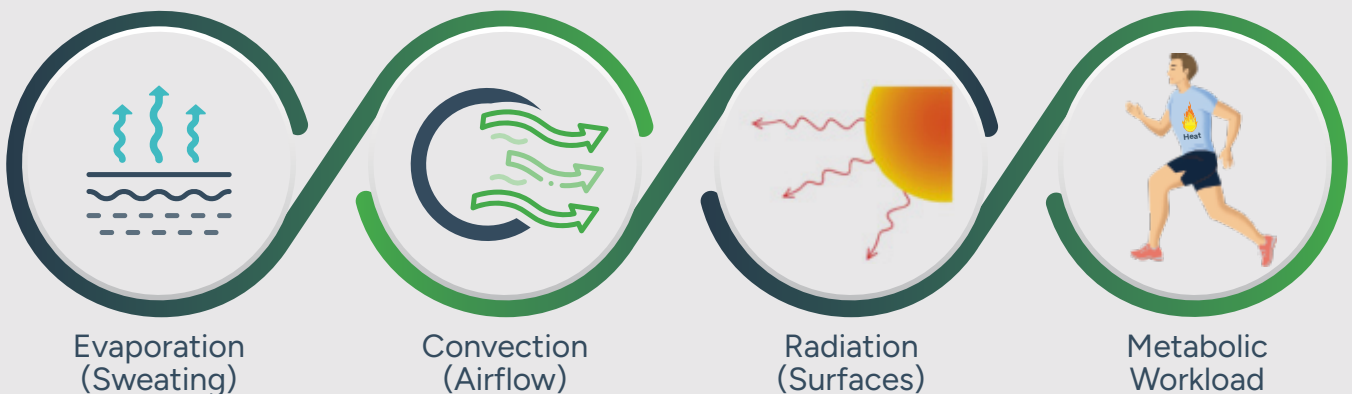
Industries with elevated exposure risk include:

- Mining operations
- Construction corridors
- Sports training facilities
- Industrial campuses
- Transport infrastructure projects

These sectors significantly rely on heat risk monitoring in workplaces to manage exposure and prevent productivity loss.

ENVIRONMENTAL PARAMETERS FOR HEAT RISK MONITORING

Air temperature only provides a partial representation of environmental heat exposure, reinforcing the need for a comprehensive workplace heat risk assessment. Human thermal strain depends on:



1. **Evaporation (Sweating):** Heat is released from the body as sweat evaporates from the skin, a process strongly influenced by humidity.
2. **Convection (Airflow):** Heat is transferred from the body to the surrounding air through air movement, with higher air velocity improving cooling efficiency.
3. **Radiation (Surfaces):** Heat is gained or lost via radiative heat transfer between the body and surrounding surfaces, as measured by globe temperature.
4. **Metabolic Workload:** Internal body heat generated during physical activity increases overall heat strain, requiring effective heat removal.

Humidity reduces evaporative cooling efficiency, while radiant heat from surfaces and sunlight significantly increases perceived exposure.

For example, a 38°C dry environment and a 38°C humid environment produce very different physiological responses. At 38°C, dry and humid environments result in significantly different heat stress levels. In dry air, effective sweat evaporation supports cooling, whereas in humid conditions, reduced evaporation leads to heat accumulation and increased physiological strain.

Therefore, occupational safety frameworks recommend composite exposure indices, such as WBGT, rather than temperature-based monitoring. Accurate heat-risk monitoring requires measurement of multiple environmental parameters influencing thermoregulation. Effective occupational heat stress monitoring requires capturing all these environmental variables in real time. The key environmental parameters that must be monitored to assess heat stress accurately include:

1. **Air Temperature:** Defines baseline environmental heat load but does not independently determine exposure risk.
2. **Relative Humidity:** Humidity affects sweat evaporation, the body's primary cooling mechanism. Higher humidity increases physiological strain even when temperature remains unchanged.
3. **Globe Temperature (Mean Radiant Temperature):** Radiant heat from sunlight, equipment surfaces, and artificial infrastructure often dominates environmental heat load in outdoor operational environments. Globe-temperature measurement enables direct quantification of this exposure component and forms a critical input to WBGT estimation.
4. **Air Velocity:** Airflow influences convective and evaporative heat loss and is particularly important in enclosed or ventilation-limited environments.
5. **Atmospheric Pressure:** Atmospheric pressure does not directly factor into WBGT calculation; however, it influences air density and ventilation effectiveness in enclosed or high-altitude environments, indirectly affecting convective and evaporative heat exchange conditions. At high altitudes, lower pressure alters convective and evaporative cooling efficiency, while in underground environments, it impacts airflow distribution and heat dissipation.

Human thermal strain is governed primarily by air temperature, radiant heat exposure, humidity, and air movement, which together determine the effectiveness of evaporative and convective heat exchange between the body and the surrounding environment (NIOSH Occupational Heat Exposure Criteria, 2016). In addition to environmental conditions, clothing insulation significantly influences heat exchange efficiency and must be considered when interpreting WBGT exposure limits in occupational environments.

HOW WBGT COMBINES ENVIRONMENTAL FACTORS FOR ACCURATE RISK ASSESSMENT

WBGT was first operationalized during the United States Army and Marine Corps training programs in the 1950s as part of a structured heat-illness prevention campaign. Its adoption significantly reduced heat-related training casualties while maintaining operational activity levels, establishing WBGT as a practical screening index for environmental heat exposure in physically demanding outdoor settings (Budd, 2008).

WBGT integrates the dry-bulb temperature, natural wet-bulb temperature, and globe temperature to estimate environmental heat exposure.

Outdoor formula: $WBGT = 0.7T_{nwb} + 0.2T_g + 0.1T_{db}$

Indoor formula: $WBGT = 0.7T_{nwb} + 0.3T_g$ (ISO 7243 methodology)

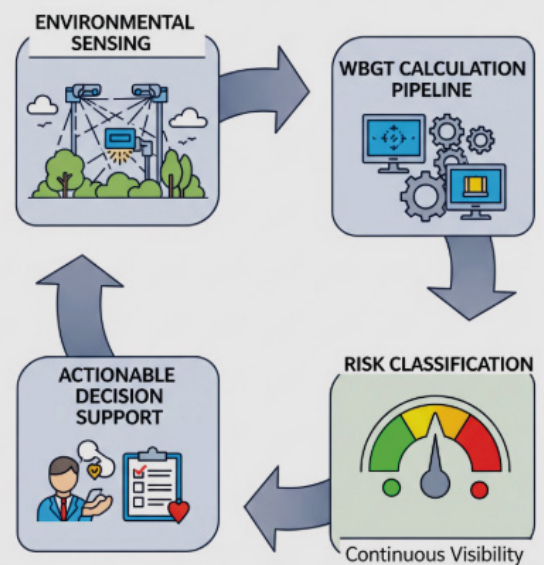
WBGT supports hydration scheduling, training modification, work-rest planning, heat-alert thresholds, and is widely used across occupational safety and sports medicine frameworks.

INTEGRATED HEAT RISK MONITORING FRAMEWORK

To manage heat exposure in the workplace, industrial heat stress management requires not only measuring individual parameters (e.g., temperature) but also an integrated framework that combines environmental sensing, data processing, and actionable decision support. Today's monitoring systems continuously monitor multiple environmental parameters to provide insight into heat exposure risks to operations.

1. System Architecture

In an integrated heat exposure monitoring system, distributed sensor nodes throughout a work site measure environmental parameters (e.g., air temperature, relative humidity, globe temperature, wind speed) that affect heat exposure. These sensor nodes are typically connected to edge devices that aggregate and pre-process collected data locally before transmitting it to centralized cloud platforms. The data collected is visualized via dashboards for real-time monitoring, historical analysis, and automatic alerts. This architecture also enables continuous visibility into environmental conditions across all operational environments, including geographically distributed locations. Along with scalable environmental heat exposure monitoring across distributed operational sites.



2. WBGT Calculation Pipeline

Basic validation and filtering are performed on raw environmental data collected from sensors deployed across the field before using it as input to calculate WBGT. Measurements from each field sensor are typically taken at specified sampling intervals to ensure measurement accuracy. Basic data-smoothing techniques can be applied to minimize the effects of transient fluctuations caused by sudden changes in environmental conditions, such as wind gusts or passing clouds near a sensor node. The processed inputs, natural wet-bulb temperature, globe temperature, and dry-bulb temperature are then used to compute WBGT values according to established formulas, enabling consistent and standardized heat-risk assessment.



Input: Temperature, Humidity, Globe Temp

WBGT Processing: Validation, Filtering, WBGT Calc

WBGT Output: WBGT Value, Risk Level

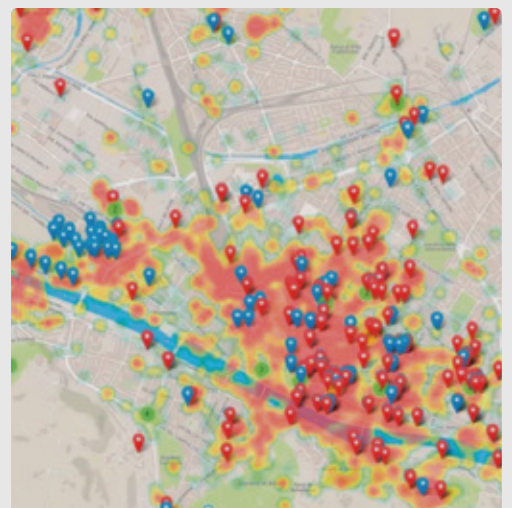
3. Risk Classification and Alert Logic

WBGT thresholds are interpreted relative to workload intensity and worker acclimatization status as defined by international occupational safety frameworks. The pre-determined risk categories of low, moderate, high, and extreme are the foundation for generating automatic alerts to notify on-site managers when temperature conditions exceed the maximum safe operational limits, with the systems generating alerts based on monitored environmental conditions. The pre-determined conditions can be configured to generate control actions, such as scheduling work-rest cycles, setting hydration requirements for workers, reducing work intensity by implementing buddy system rules, and suspending work operations in extreme conditions. Thus, the monitoring systems will continuously provide reliable environmental information to make immediate decisions regarding safe operations. Such automated systems are essential for effective heat risk monitoring in workplaces, enabling real-time safety interventions.



4. Spatial Monitoring and Heat Mapping

The environmental heat exposure experienced at various locations within a site can vary significantly depending on the amount of sun exposure, the materials of the surfaces, the heat emitted from equipment, and the airflow patterns in that area. To account for the differences, many monitoring nodes are installed throughout a representative area. The data collected from the monitoring nodes can be displayed as spatial heat maps to show local hotspots and high-risk areas. This information provides spatial data that will help with targeted interventions, effective staffing of employees across the complexity of the operation, and overall better mitigation of heat exposure in complex work environments.



STANDARDS AND REGULATORY FRAMEWORKS SUPPORTING WBGT MONITORING

WBGT monitoring is supported across multiple international occupational safety frameworks.

1. **ISO 7243:2017** recommends WBGT as a screening index for environments involving solar radiation and moderate-to-heavy workloads.

| Workload | Screening WBGT |
|----------|----------------|
| Light | 30°C |
| Moderate | 28°C |
| Heavy | 26°C |

2. Industrial hygiene guidance frameworks recognize WBGT as the primary environmental screening indicator used before applying detailed physiological heat-strain modeling methods, such as Predicted Heat Strain.
3. **ISO 7933** ISO 7243 provides WBGT-based screening assessment, while ISO 7933 applies Predicted Heat Strain (PHS) modeling when detailed physiological evaluation is required beyond screening-level assessment.

4. **ACGIH Threshold Limit Values** recommended WBGT limits for acclimatized workers:

| Workload | WBGT Limit |
|------------|------------|
| Light | 30°C |
| Moderate | 28°C |
| Heavy | 26°C |
| Very heavy | 25°C |

Unacclimatized workers require thresholds typically 2–3°C lower.

5. **NIOSH Occupational Heat Exposure Criteria** recommends WBGT monitoring for acclimatization planning, hydration scheduling, and work-rest cycles.
6. **DGMS India (Mining Sector)** recommends monitoring the dry-bulb temperature, wet-bulb temperature, and air velocity. These parameters form the environmental basis of WBGT assessment frameworks.
7. **Sports Safety Frameworks:** WBGT thresholds are used by World Athletics, FIFA, and the American College of Sports Medicine

| WBGT | Risk Level | Recommended Action |
|---------|------------|--------------------|
| <26°C | Low | Normal activity |
| 26–29°C | Moderate | Hydration breaks |
| 29–32°C | High | Reduce intensity |
| >32°C | Extreme | Suspend activity |

“International safety standards consistently recommend WBGT as the screening index for occupational heat exposure.”

Epidemiological analyses show that the probability of heat-related illness increases significantly when WBGT exceeds approximately 27°C, supporting the use of threshold-based alert systems in occupational monitoring programs (Urban Climate exposure-response dataset, 2025).

WBGT is widely used as a screening-level environmental heat-stress index rather than a complete predictor of physiological strain. Interpretation of WBGT thresholds should consider additional factors, including workload intensity, clothing insulation, hydration status, and acclimatization level. When combined with these operational variables, WBGT provides a reliable basis for structured heat-risk mitigation strategies (Budd, 2008).

■ THE IMPORTANCE OF INTEGRATED ENVIRONMENTAL MONITORING SYSTEMS

Environmental heat exposure varies significantly within the same operational site due to surface reflectivity, equipment heat emissions, terrain variation, ventilation differences, and solar exposure variability. Regional weather-station data cannot capture these localized conditions. Site-level monitoring enables identification of exposure hotspots influencing worker safety outcomes. Radiant heat exposure frequently dominates environmental heat load in outdoor environments.

Recent environmental heat-exposure datasets demonstrate that thermal conditions can vary significantly across short spatial distances due to surface materials, shading, terrain configuration, and surrounding infrastructure, reinforcing the importance of site-level WBGT monitoring rather than reliance on regional weather-station observations (Nature Scientific Data, 2025). Monitoring stations equipped with globe-temperature sensing capability enable:

- Accurate WBGT estimation
- Improved exposure classification
- Alignment with ISO methodologies

Integrated environmental monitoring platforms such as those developed by Oizom support direct radiant heat measurement across distributed operational environments where temperature-only monitoring approaches are insufficient.

■ INDUSTRY APPLICATIONS OF OCCUPATIONAL HEAT RISK MONITORING

WBGT exposure varies across operational zones depending on solar loading, surface conditions, airflow behavior, and workforce activity patterns. Monitoring stations should be deployed across representative exposure environments, including:

- Activity corridors
- Rest shelters
- Equipment-dense areas
- Ventilation-limited spaces
- Open operational zones

Typical deployment environments include:

- Mining operations
- Stadium complexes
- Construction sites
- Industrial campuses
- Transport infrastructure corridors
- Utilities maintenance zones

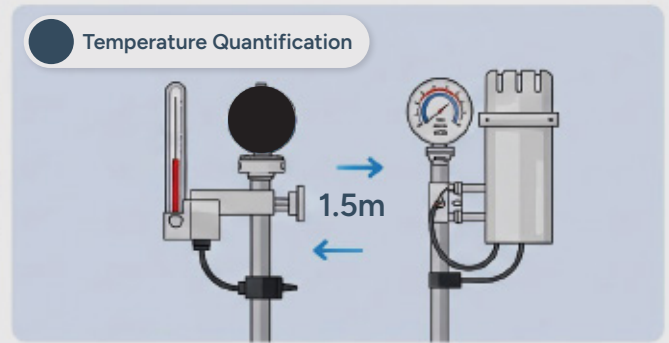
Distributed monitoring improves exposure visibility and supports threshold-based safety decisions aligned with international heat-stress management frameworks.

■ REAL-WORLD EXAMPLE: CONSTRUCTION SITE HEAT EXPOSURE

A large-scale construction project operating under peak-summer conditions demonstrates the practical value of integrated heat-risk monitoring. Midday environmental readings indicated an air temperature of 40°C, relative humidity of 60%, and elevated globe temperature due to direct solar radiation, resulting in a calculated WBGT of approximately 31°C, which falls within the high-risk category for moderate-to-heavy workloads.

Under these conditions, reduced evaporative cooling and increased radiant heat exposure significantly elevate physiological strain on workers. Using real-time WBGT monitoring, site managers implemented targeted interventions, including adjusted work-rest cycles based on task intensity, mandatory hydration breaks at 15-20 minute intervals, rescheduling high-intensity activities to cooler periods, and activating shaded rest areas. This highlights the effectiveness of real-time heat risk monitoring in workplaces.

IMPLEMENTING A WORKPLACE HEAT MONITORING STRATEGY



1. Determine Exposure Zones

Identify “high-risk” areas on sites, such as open work areas, densely packed equipment areas, and areas with limited ventilation, where heat can build up.

2. Establish Methods for WBGT Measurement

Establish measurement stations that can quantify temperature, humidity, globe temperature, and wind speed to estimate WBGT. Sensors should be placed at a height representative of worker exposure (approximately 1.5 meters above ground), as installation location is a critical factor in determining how accurately measurements reflect the actual environmental conditions experienced by workers. The use of shaded, non-obstructed sensors will yield inaccurate WBGT measurements. Ensure that the readings from WBGT measurement devices reflect current environmental conditions. Integrated measurement platforms enable multiple WBGT measurements within a single deployment method, consistent with methodologies for estimating WBGT.

3. Ensure system accuracy and reliability

The reliability of heat risk assessments depends on consistent data collection. Monitoring systems must be calibrated at regular intervals to ensure data accuracy, as sensor drift occurs over time due to environmental exposure. Regularly testing and validating the performance and reliability of monitoring equipment will ensure that the collected data will be reliable over time, supporting sound decision-making.

4. WBGT Alert Threshold Integration

WBGT thresholds should be based on existing standards to enable integration with operational safety procedures. By integrating WBGT alert threshold outputs into day-to-day safety compliance operations, the environmental conditions associated with WBGT are used to implement timely, effective risk mitigation measures.

■ FUTURE OF OCCUPATIONAL HEAT MONITORING

Heat-risk monitoring systems are evolving from reactive measurement tools into predictive safety platforms. Increasingly, these systems integrate real-time on-site environmental data with weather forecasts to enable AI-assisted exposure prediction, allowing organizations to anticipate high-risk conditions before they occur rather than responding after thresholds are exceeded.

Advancements in wearable sensor technologies are further strengthening heat-risk assessment by incorporating physiological indicators such as core body temperature and heart rate, providing a more direct understanding of individual worker strain in addition to environmental exposure. This enables a more personalized and responsive approach to heat safety management.

In parallel, AI-based risk-scoring models are emerging that combine environmental parameters, workload intensity, and historical exposure data to generate dynamic risk levels and automate safety recommendations. These systems support climate-adaptive scheduling, allowing organizations to adjust work patterns, shift timings, and resource allocation based on predicted heat conditions.

As climate variability increases, continuous and integrated monitoring infrastructure will play a critical role in enabling proactive, data-driven workforce protection strategies across heat-exposed industries.

CONCLUSION

Occupational heat exposure represents a growing safety and operational challenge across climate-exposed industries. WBGT provides a scientifically validated framework for assessing environmental heat exposure aligned with international occupational safety guidance. Integrated environmental monitoring platforms capable of measuring temperature, humidity, airflow, and globe temperature enable accurate WBGT estimation across distributed operational environments. As industries adapt to rising temperatures, industrial heat stress management and heat risk monitoring in workplaces will become essential components of safety strategy. Monitoring infrastructure equipped with globe-temperature sensing capability supports safer workforce operations, improved regulatory readiness, and climate-resilient workplace planning.

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