WET BULB GLOBE TEMPERATURE (WBGT) WITHOUT THE WET BULB

APPLICATION NOTE QUEST-003 (US)

Introduction

The TSI® Incorporated (TSI®) QUESTemp° 44/46 Heat Stress Monitors offer traditional heat stress monitoring without the hassles of maintaining a wet bulb. Through collaboration with Dr. Thomas Bernard at the University of South Florida, mathematical models have been implemented to create a virtual waterless wet bulb through a combination of dry bulb temperature, globe temperature, air flow rate and humidity measurements. The data presented in this application note demonstrates that the waterless wet bulb can be used to calculate a reasonable estimate of Wet Bulb Globe Temperature (WBGT).

About the Wet Bulb Globe Temperature

Over the years, the wet bulb globe temperature index (WBGT) has become the most prevalent method for measuring environmental factors related to heat stress (1). The WBGT has been adopted as an index of climatic conditions in industrial settings by the recommendation of the American Conference of Governmental Industrial Hygienists (ACGIH). Quest™ Technologies, now owned by TSI® Incorporated, first offered instruments to monitor heat stress via WBGT in 1991. While devices to measure WBGT have become widely used, those required to operate the instruments have begrudged the need to maintain the water level and fight wick contamination in the wet bulb. With the QUESTemp° 44 and 46 heat stress monitors, users are not inconvenienced with these issues.

Measurement Methods

Calculating WBGT

The WBGT is a weighted average of three temperature sensors: a globe (G) thermometer, a wet bulb (WB) thermometer, and a dry bulb (DB) thermometer. The WBGT is calculated through one of the formulas indicated in Figure 1 depending on the environment.

WBGT (Indoor) = 0.7WB + 0.3G
WBGT (Outdoor) = 0.7WB + 0.2G + 0.1DB

Figure 1: WBGT calculations
WBGT formulas for either indoor or outdoor measurements.

Once calculated, these values are comparable to indices of work-rest regimens (stay times) based upon workloads.

About the Models

In the case of the QUESTemp° 44/46 heat stress monitors, the globe temperature provides an indication of the radiant heat exposure on an individual due to either direct sunlight or hot objects in the environment. The dry bulb thermometer measures the ambient air temperature. While the globe and dry bulb are measured as before, the wet bulb temperature is estimated using a mathematical model. The model used is a wind-adjusted version of the psychrometric wet bulb (2). The comparison between the models and the scientific data results of the wind adjustments are identified in Table 3 of Bernard and Pourmoghani, "Prediction of Workplace Wet Bulb Global Temperature" (2). For the case where an air probe is not attached to the QUESTemp° 44/46 heat stress monitors, the current environment's wind speed is inputted by the end user. The instrument's recommended air flow setting for indoor is 0.3 m/s and 2.0 m/s for outdoor.

Methods

Three Data Collections

Data was collected under three different sets of conditions. For each set of conditions, a waterless sensor bar was installed as the primary sensor bar in a QUESTemp° 46 heat stress monitor and a sensor bar with a wet bulb was installed as the secondary sensor bar for direct comparison. The Air-Probe 9 was also connected to the instrument to allow air flow rate corrections. Data was collected at one minute intervals in both daytime and nighttime scenarios.

Figure 2: QUESTemp° 46

The first data collection was measured in the laboratory. For this set, the instruments were placed within an environmental chamber and the temperature was varied from 5°C to 60°C and humidity was varied from 19 percent to 97 percent relative humidity. With the first data collection, there was minimal radiant heat and the chamber circulation fan provided varying air movement over time.

The second data collection was measured under outdoor conditions. For this set, data was taken during both daytime and nighttime hours over differing thermal loads (stone, grass, and asphalt) and weather conditions.

The third data collection was taken in an enclosed environment with high radiant heat and no air flow to evaluate the efficacy of the calculated wet bulb under a worst-case scenario.

In Table 1 and Table 2, a Combined data set is listed in the Data Set column. In Table 1, the Combined data set consists of the data from the Laboratory, Outdoor, and No Air Flow data collections. In Table 2, the Combined data set consists of the data from the Laboratory and Outdoor conditions.

Results

Wet Bulb vs. Waterless Wet Bulb

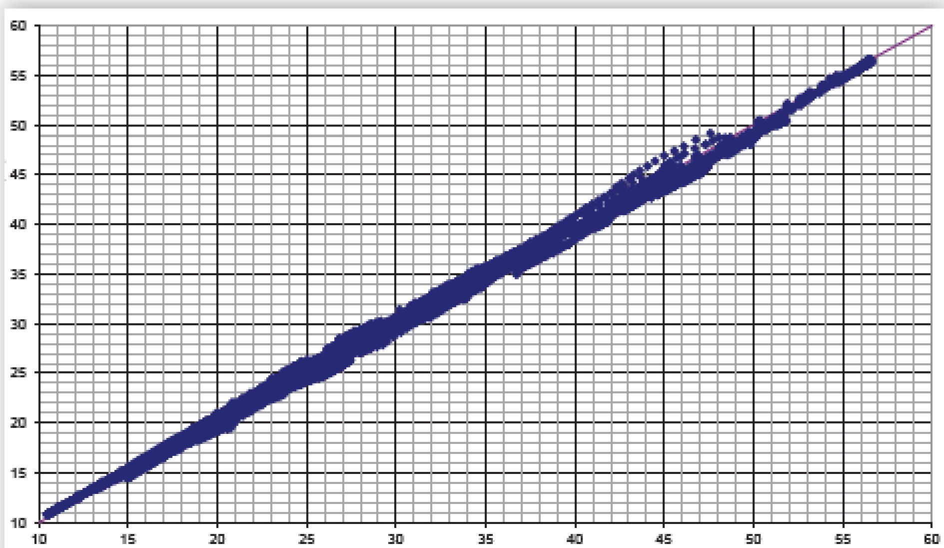
The results showed that under normal conditions, the calculated wet bulb led to WBGT values which were within acceptable tolerances. Table 1 and Figure 3 show the differences between the WBGT temperatures with a measured and calculated wet bulb across all data sets. Table 1 and Table 2 list the standard deviation (Std. Dev.) and the root mean square error (RSME) of the data sets.

Table 1: Comparison of difference between WBGT temperatures using a measured wet bulb and waterless bulb.

Data Set	Std. Dev.	RMSE
Laboratory	0.25°C	0.39°C
Outdoor	0.33°C	0.42°C
No Air Flow	0.56°C	0.96°C
Combined	0.52°C	0.53°C

Scatter of WBGT Temperature Using Calculated Wet Bulb vs. Measured Wet Bulb (all data sets)

WBGT with Calculated Wet Bulb (°C)



WBGT with Measured Wet Bulb (°C)

Figure 3: WBGT measurements (all data sets)
WBGT temperatures with a measured and calculated wet bulb across all data sets.

Wet Bulb Data Sets

Across all data sets there was a mean deviation of 0.11°C, which is well within the margin of error for the instrument. The measurement uncertainty for the combined data set was calculated as u_c = 0.54°C. Using a coverage factor of k = 2, the expanded measurement uncertainty was calculated as U = 1.1°C. This uncertainty was determined from a combination of supplied sensor specifications and statistical analysis of the wet bulb differences.

It has been argued that the enclosed windless condition is unrealistic due to the complete lack of air flow. Worker movement alone should create some air movement. If we accept this premise and remove the windless data set, our differences are even smaller, as seen in Table 2 and Figure 4.

Table 2: Comparison of difference between WBGT temperatures using a naturally aspirated wet bulb and a waterless wet bulb (excludes No Air Flow data set).

Data Set	Std. Dev.	RMSE
Laboratory	0.25°C	0.39°C
Outdoor	0.33°C	0.42°C
Combined	0.33°C	0.42°C

Scatter of WBGT Temperature Using Calculated Wet Bulb vs. Measured Wet Bulb (excludes No Air Flow data set)

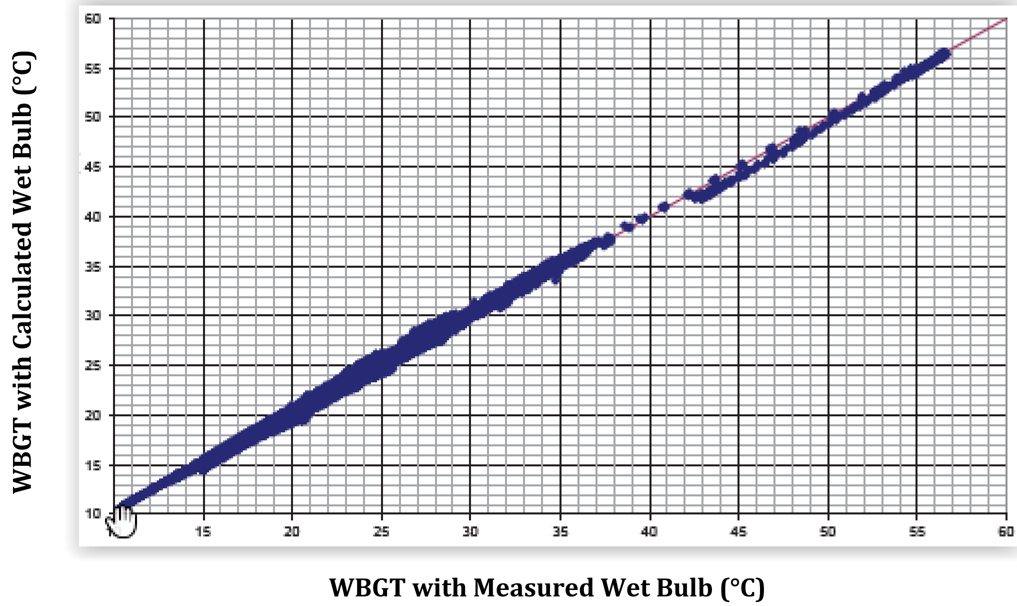


Figure 4: WBGT measurements (excludes No Air Flow data set)
WBGT temperatures with a natural wet bulb and a waterless wet bulb.

Measuring with Waterless Wet Bulb: Considerations

While the waterless wet bulb worked well, there are conditions such as areas with no air movement, dynamic changes in the environment, and condensing environments which should be avoided, if possible, to minimize measurement bias.

Areas with No Air Movement

As seen in the third data set, measurements in areas with no air movement will tend to be underreported by approximately one degree Celsius. This condition can rarely be found in a real-world environment, as worker movement itself will create some flow of air. For this reason, the QUESTemp° 44/46 heat stress monitor without the AirProbe-9 attachment defaults to a minimum air flow rate of 0.3 m/s (indoor) and 2.0 m/s (outdoor).

Dynamic Changes in the Environment

The calculated wet bulb model performs best in steady-state conditions. Sudden changes in conditions can momentarily increase the bias of the estimator while the system adjusts.

Condensing Environments

If water condenses on the humidity sensor, a recoverable bias will be introduced to the estimator.

Summary

The data presented demonstrates the efficacy of WBGT measurements using a calculated wet bulb in place of a measured wet bulb. While using a measured wet bulb is the gold standard and should always be considered, this change is desirable for many situations where wet bulb maintenance is impractical. Under normal conditions, values were well within an acceptable margin of the measured WBGT temperature; however, the expanded measurement uncertainty was calculated as 1.1°C. Care should be taken to note situations where there is no air flow or rapidly changing conditions, as these conditions lead to the greatest discrepancies with the waterless wet bulb heat stress units.

Cited Sources

1. U.S. Dept. of Labor, Occupational Safety & Health Administration, Heat Stress. *OSHA Technical Manual III*:**4** (1999).

2. Bernard, T.E. and Pourmoghani, M., Prediction of Workplace Wet Bulb Global Temperature. *Appl. Occ. Env. Hyg.* **14**:126-134 (1999).

Pertinent References

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- Taylor, B.N and Kuyatt, C.E, Guidelines for Evaluating and Expressing the Uncertainty of NIST Measurement Results. *NIST Technical Note* 1297 (1994).

- Bernard, T.E and Cross, R.R., Heat Stress Management: Case Study in an Aluminum Smelter. *International Journal of Industrial Ergonomics*.

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