WBGT without the wet bulb

Demonstrating the efficacy of WBGT measurements using a calculated wet bulb in place of a measured wet bulb...

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] Now Quest Technologies, a 3M company, offers an alternative technology. 3M™ QUESTemp°™ QT44 and QT46 offer all the functions of traditional WBGT heat stress monitoring without the nuisance 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, humidity, and wind speed measurements. This waterless wet bulb is then used to calculate a reasonable estimate of WBGT.

Introduction

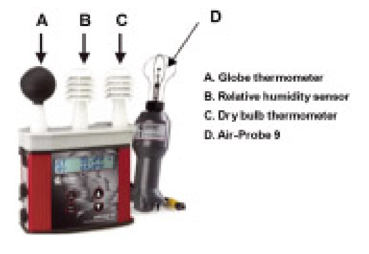
3M Quest Technologies first offered devices to monitor heat stress using WBGT in 1991. While devices to measure WBGT have become commonplace, those required to operate the instruments have begrudged the need to maintain the water level and fight wick contamination in the wet bulb. With the introduction of the QUESTemp° 44 and 46, users no longer need to be inconvenienced with these issues.

Description of models

WBGT can easily be calculated through the following formula.

$$WBGT=0.7*T_{nWB}+0.2*T_{GT}+0.1*T_{DB}$$

In the case of the QUESTemp° 44/46, the globe and dry bulb temperatures are measured as before, however the wet bulb temperature is estimated using a mathematical model that is a wind-adjusted version of the psychrometric wet bulb.[2] For a description of the model and how the wind adjustments are performed, see Bernard's website.[3] For the case where an air-probe is not attached to the QT 44/46, the wind speed is computed by setting the airflow to the current environment's wind speed. The instrument's recommended airflow setting for indoors is 0.3m/s and 2.0m/s for outdoor.



Caption: QUESTemp° 44 with Air-Probe 9

Methods

Data was collected under three different sets of conditions:

- The first set was taken in the laboratory. Instruments were placed within an environmental chamber and the temperature was varied from 5°C to 60°C; humidity was varied from 19% to 97% relative humidity. There was minimal radiant heat and the chamber circulation fan provided varying air movement over time;
- The second set was taken under outdoor conditions. Data was taken during both daytime and night time hours over differing thermal loads (stone, grass, and asphalt) and weather conditions;
- The last dataset was taken in an enclosed environment with high radiant heat and no air flow in order to evaluate the efficacy of the calculated wet bulb under a worst-case scenario.

For each set of conditions, a waterless sensor bar was installed as the primary sensor bar in a QT46 and a sensor bar with wet bulb was installed as

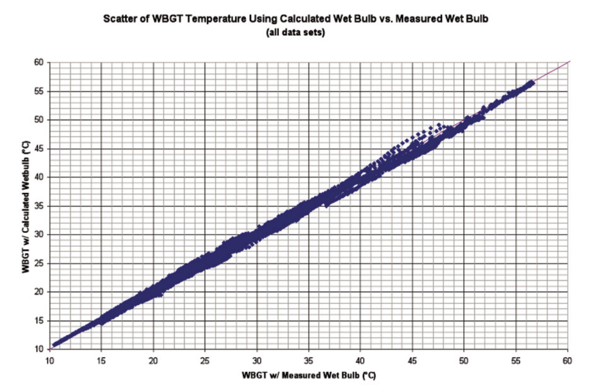


Fig. 1: Scatter plot for all collected datasets of WBGT temperature calculated from the waterless wet bulb temperature versus measured natural wet bulb temperature

DataSet	Std.Dev.	RMSE
Laboratory	0.25 °C	0.39 °C
Outdoor	0.33 °C	0.42 °C
No Airflow	0.58 °C	0.96 °C
Combined	0.52 °C	0.53 °C

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

the secondary sensor bar for direct comparison. An Air-Probe 9 was also connected to the instrument to allow wind corrections. Data was collected at one minute intervals in both daytime and night time scenarios.

Results

Wet bulb vs waterless wet bulb

The results showed that under normal conditions, the calculated wet bulb led to WBGT values that were within acceptable tolerances. Table 1 and Fig. 1 show the differences between the WBGT temperatures with a measured and calculated wet bulb across all datasets.

Across all datasets 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 dataset was calculated as uc = 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 airflow. Worker movement alone should create some air movement. If we accept this premise and remove the windless dataset, our differences are even smaller, as seen in Table 2 and Fig. 2.

While the waterless wet bulb worked well, there are a few conditions that should be avoided if possible to minimise measurement bias.

Areas with no air movement

As seen in the third dataset, 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 will create some flow of air.

Dynamic changes in the environment

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

Table 2: Comparison of difference between WBGT temperatures using a naturally aspirated wet bulb and a waterless wet bulb

The 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.

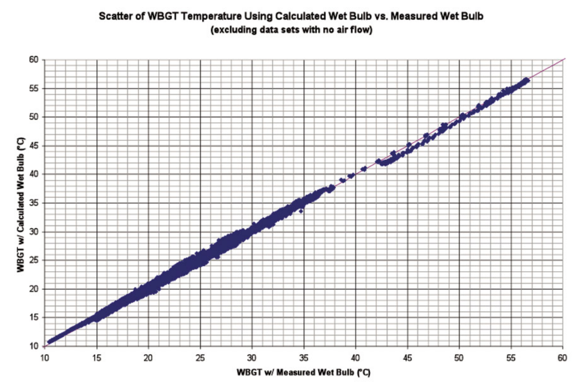


Fig. 2: Scatter plot of WBGT temperature calculated with waterless wet bulb temperature versus measured natural wet bulb temperature excluding data from the enclosed environment with no air flow

Condensing environments

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

> "3M Quest Technologies first offered devices to monitor heat stress using WBGT in 1991."

Summary

The data 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 however to note situations where there is no airflow or rapidly changing conditions, as these conditions lead to the greatest discrepancies with the waterless wet bulb heat stress units.

References

1. US Dept of Labor, Occupational Safety & Health Admin, Heat Stress. OSHA Technical Manual III:4
2. T E Bernard, and M Pourmoghani, Prediction of Workplace Wet Bulb Global Temperature, Appl. Occ. Env. Hyg, 14:126-134 (1999)
3. http://personal.health.usf.edu/tbernard/thermal
4. B N Taylor, and C E Kuyatt, Guidelines for Evaluating and Expressing the Uncertainty of NIST Measaurement Results, NIST Technical Note 1297, 1994 Edition
5. T E Bernard, and R R Cross, Heat Stress Management: Case Study in an Aluminum Smelter. International Journal of Industrial Ergonomics

3M | QUEST TECHNOLOGIES now part of 3M

Quest Technologies, a 3M company
1060 Corporate Center Drive
Oconomowoc
WI 53066

Tel: +1 262 567 9157
Fax +1 262 567 4047

3Mdetectionmail@mmm.com
www.questtechnologies.com