WET BULB GLOBE TEMPERATURE MEASUREMENT AT THE Y-12 NATIONAL SECURITY COMPLEX

Thomas E. Bellinger, CCM
Y-12 National Security Complex
Oak Ridge, Tennessee

1. INTRODUCTION

To better serve the needs of the Fire Services, Industrial Hygiene and the overall Y-12 National Security Complex (Y-12 NSC) plant population regarding heat stress, globe temperature sensors were installed at both Y-12 NSC meteorological towers. Temperature data from these sensors combined with other meteorological parameters are used to determine the wet bulb globe temperature (WBGT). The WBGT, also referred to as the WBGT Index, is a composite temperature used to estimate the effect of temperature, humidity, wind speed and solar radiation on humans. The WBGT is used to determine appropriate exposure and activity levels to high temperatures. This paper documents the WBGT project, components used, installation, costs, suppliers, as well as the data obtained during the summer of 2009 and how it is used at the Y-12 NSC. The overall goal is to improve heat stress awareness of the Y-12 NSC plant population, provide Fire Services and Industrial Hygiene with needed heat stress information, and provide a historical archive of measurable WBGT.

2. BACKGROUND

The U.S. Occupational Safety and Health Administration uses the WBGT for identifying environmental conditions under which individuals are likely to experience heat stress effects and for implementing protective controls to prevent heat related injuries. The WBGT was initially developed by the United States Marine Corps at Parris Island in 1956 to reduce heat stress injuries in recruits and has been revised several times. Figure 1 shows the U.S. Army work/rest guidelines including the heat category determined by the WBGT. Similar tables using the WBGT have been developed for numerous activities ranging from work to play. The internationally accepted standard that provides a simple method for the assessment and control of hot environments is ISO 7243, "Hot Environments – Estimation of the Heat Stress on Working Man, Based on the WBGT Index". The overall goal is to use the WBGT to provide information when heat related injuries are likely to occur.

Corresponding author address: Thomas E. Bellinger, Y-12 National Security Complex, PO Box 2009, Building 9115, MS8219, Oak Ridge TN 37831-8219. Email: bellingerte@y12.doe.gov

The WBGT is derived from one of the following formulas:

With direct exposure to sunlight:

$$WBGT_{outside} = 0.7Tw + 0.2Tg + 0.1Td$$

Without direct exposure to the sun:

$$WBGT_{inside} = 0.7Tw + 0.3Tg$$

Where:

Tw = Natural wet-bulb temperature
Tg = Globe temperature
Td = Ambient air temperature

For this project, only the $WBGT_{outside}$ was derived for both Y-12 NSC tower sites using measured meteorological parameters. It should be noted that the WBGT can also be reasonably estimated using standard meteorological measurements (Liljegren, 2008 & Hunter, 1999).

3. SENSORS AND INSTALLATION

ISO 7243 and the OSHA Technical Manual, Section III, Chapter IV, Heat Stress provides the specifications for the equipment to be used. Given that the Y-12 NSC meteorological program already meets American National Standards Institute and U.S. Environmental Protection Agency meteorological standards, the wet-bulb temperature was derived using the measured ambient temperature and relative humidity using the following equations:

$$T_{dc} = ((T_c - (14.55 + 0.114 * T_c) * (1 - (0.01 * RH)) - ((2.5 + 0.007 * T_c) * (1 - (0.01 * RH))) ^ 3 - (15.9 + 0.117 * T_c) * (1 - (0.01 * RH)) ^ 14))$$

$$E = (6.11 * 10 ^ (7.5 * T_{dc} / (237.7 + T_{dc})))$$

$$WB_c = (((0.00066 * P) * T_c) + ((4098 * E) / ((T_{dc} + 237.7) ^ 2) * T_{dc})) / ((0.00066 * P) + (4098 * E) / ((T_{dc} + 237.7) ^ 2))$$

Where: T_c = Temperature in degrees C
RH = Relative Humidity in form 88 not 0.88
T_{dc} = Dew point in degrees C
E = Saturation vapor pressure
WB_c = Wet Bulb Temperature in degrees C
P = Pressure in mb

The globe temperature is the temperature at the center of a 15 cm (6-inch) diameter hollow copper sphere (mean emission coefficient of 0.95) painted on the outside with a matte black finish. It is important that the sphere is 15 cm in diameter, is not shaded, and air flow is not obstructed around it. The bulb or sensor of a thermometer (range -5°C to +100°C with an accuracy of ±0.5°C) must be fixed in the center of the sphere.

To fulfill these specifications, two Novalynx Globe Thermometers (Model 210-4417NT) were purchased for $250 each. This model provides just the black hollow copper sphere with no thermometer or sensor. A rubber stopper with a hole for the temperature sensor was also included. Two Climatronics 100093 temperature sensors were purchased for $140 each. The temperature sensor was inserted into the rubber stopper so that it was located in the center of the globe. This allows the temperature sensor to be easily removed for calibration. Small pieces of angled aluminum were purchased and attached near the existing solar radiation sensor at the Y-12 NSC meteorological tower sites to mount the globe. These locations provided good air flow around the globe and no shadows from nearby obstacles. A ½ inch thick piece of black foam rubber was placed between the globe and the aluminum mounting to minimize thermal effects from the mounting. Existing spare wires, spare ports on the lightning suppressor, and a spare Met I/O card were used to connect the sensor to the site data logger. The data logger was easily programmed to accommodate the new temperature sensor. Hourly, 15-minute, and 1-minute averages of globe temperature data are collected. Figure 2 shows the overall globe temperature installation at one of the Y-12 NSC meteorological towers.

4. OPERATIONAL IMPLEMENTATION

At the end of each 15-minute averaging period, the WBGTs were derived for both Y-12 NSC tower sites using the respective measurement of globe temperature, ambient temperature and wet bulb temperature. All meteorological data including the WBGTs are easily accessed by the Y-12 NSC plant population through an intranet website developed for the meteorological system. To improve heat stress awareness of the Y-12 NSC plant population, the website also displays a color coded heat stress category as needed at the top of each page and a link to the heat stress categories. Conservative heat stress categories were developed by Y-12 NSC Industrial Hygiene personnel and are shown in Figure 3. The WBGTs are also archived to provide a historical record of measured WBGTs at the Y-12 NSC.

5. SUMMER 2009 WBGT DATA

Table 1 shows a summary of temperature and heat stress parameters from June 1 through August 31, 2009. A cooler than normal summer provided few periods of high heat stress but numerous periods of moderate or slight heat stress. During this period, the ambient temperature reached 90°F or more for only about 40 total hours. Figure 4 shows a graph of the various temperature parameters for a ten day period in June 2009.

	West Tower	PSS Tower
Maximum Ambient Temperature	90.6°F	93.7°F
Maximum Globe Temperature	127.1°F	122.0°F
Maximum WBGT	86.9°F	86.8°F
High Heat Stress	0.35%	0.59%
Moderate Heat stress	29.97%	33.13%
Slight Heat Stress	30.21%	31.02%

Table 1. A summary of temperature and heat stress parameters measured at the Y-12 NSC meteorological towers for the period June 1 – August, 2009.

6. SUMMARY

The small cost and ease of installation of globe thermometers to existing meteorological sites can provide WBGT measurements needed for heat stress. This project can easily be duplicated at other sites to improve heat stress awareness and implement protective controls to prevent heat related injuries.

Work/Rest and Water Consumption Table

Applies to average sized, heat-acclimated soldier wearing BDU, hot weather. (See TB MED 507 for further guidance.)

Easy Work	Moderate Work	Hard Work
• Weapon Maintenance • Walking Hard Surface at 2.5 mph, < 30 lb Load • Marksmanship Training • Drill and Ceremony • Manual of Arms	• Walking Loose Sand at 2.5 mph, No Load • Walking Hard Surface at 3.5 mph, < 40 lb Load • Calisthenics • Patrolling • Individual Movement Techniques, i.e., Low Crawl or High Crawl • Defensive Position Construction	• Walking Hard Surface at 3.5 mph, ≥ 40 lb Load • Walking Loose Sand at 2.5 mph with Load • Field Assaults

Heat Category	WBGT Index, F°	Easy Work		Moderate Work		Hard Work	
		Work/Rest (min)	*Water Intake (qt/hr)*	*Work/Rest (min)*	*Water Intake (qt/hr)*	*Work/Rest (min)*	*Water Intake (qt/hr)*
1	78° - 81.9°	NL	½	NL	¾	40/20 min	¾
2 (GREEN)	82° - 84.9°	NL	½	50/10 min	¾	30/30 min	1
3 (YELLOW)	85° - 87.9°	NL	¾	40/20 min	¾	30/30 min	1
4 (RED)	88° - 89.9°	NL	¾	30/30 min	¾	20/40 min	1
5 (BLACK)	> 90°	50/10 min	1	20/40 min	1	10/50 min	1

- The work/rest times and fluid replacement volumes will sustain performance and hydration for at least 4 hrs of work in the specified heat category. Fluid needs can vary based on individual differences (± ¼ qt/hr) and exposure to full sun or full shade (± ¼ qt/hr).
- **NL** = no limit to work time per hr.
- **Rest** = minimal physical activity (sitting or standing) accomplished in shade if possible.
- ***CAUTION: Hourly fluid intake should not exceed 1½ qts.***

  Daily fluid intake should not exceed 12 qts.
- If wearing body armor, add **5°F** to WBGT index in humid climates.
- If doing Easy Work and wearing NBC (MOPP 4) clothing, add **10°F** to WBGT index.
- If doing Moderate or Hard Work and wearing NBC (MOPP 4) clothing, add **20°F** to WBGT index.

For additional copies, contact: U.S. Army Center for Health Promotion and Preventive Medicine Health Information Operations Division at (800) 222-9698 or CHPPM - Health Information Operations@apg.amedd.army. mil.
For electronic versions, see http://chppm-www.apgea.army.mil/heat. Local reproduction is authorized.
June 2004

CP-033-0404

Figure 1. U.S. Army work/rest guidelines including the heat category determined by the WBGT

Figure 2. Globe temperature installation at one of the Y-12 NSC meteorological towers

Heat Stress Information

Heat Stress Category	WBGT Index, °F	Description
Slight (YELLOW)	70.0° - 74.9°	recognize that heat stress may be possible
Moderate (ORANGE)	75.0° – 84.9°	job specific heat stress monitoring or physiological monitoring should be conducted
High (RED)	>= 85.0°	heat stress likely without proper work rest regimes or physiological monitoring

Figure 3. WBGT based color coded heat stress categories used at the Y-12 NSC.

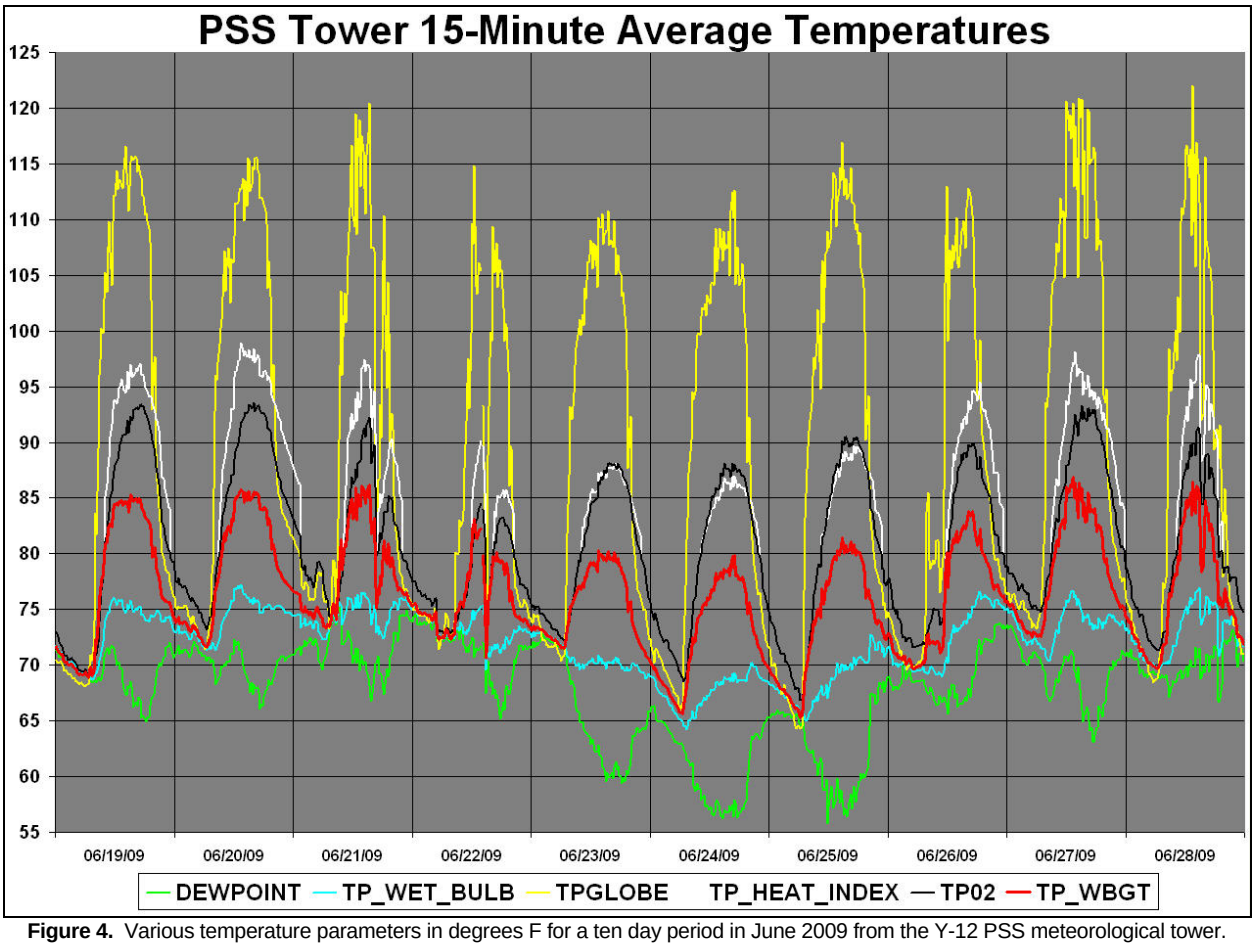

Figure 4. Various temperature parameters in degrees F for a ten day period in June 2009 from the Y-12 PSS meteorological tower.

7. REFERENCES

Liljegren, James C., Carhart, Richard A., Lawday, Phillip, Tschoop, Stephen, and Sharp, Robert (2008) *'Modeling the Wet Bulb Globe Temperature Using Standard Meteorological Measurements*', Journal of Occupational and Environmental Hygiene, 5:10, 645-655

Department of Energy (DOE), Office of Scientific and Technical Information (OSTI): *Estimating Wet Bulb Globe Temperature Using Standard Meteorological Measurements* by C. H. Hunter, C. O. Minyard (WSRC-MS-99-00757). Oak Ridge, Tenn.:DOE, OSTI, 1999.
http://sti.srs.gov/fulltext/ms9900757/ms9900757.pdf

Occupational Safety and Health Administration (OSHA) *Heat Stress. In OSHA Technical Manual, Section III, Health Hazards, Chapter 4*. Washington, D.C., Office of Science and Technology Assessment, 1999.
http://www.osha.gov/dts/osta/otm/otm_toc.html

DISCLAIMER

COPYRIGHT NOTICE

WET BULB GLOBE TEMPERATURE MEASUREMENT AT THE Y-12 NATIONAL SECURITY COMPLEX

Thomas E. Bellinger, CCM
Y-12 National Security Complex
Oak Ridge, Tennessee

To better serve the needs of the Y-12 Fire Services, Industrial Hygiene and the plant population regarding heat stress, globe temperature sensors were installed at both Y-12 meteorological towers. Temperature data from these sensors combined with other meteorological parameters are used to determine the wet bulb globe temperature (WBGT). The WBGT is a composite temperature used to estimate the effect of temperature, humidity, wind speed and solar radiation on humans. The WBGT is used to determine appropriate exposure and activity levels to high temperatures. This presentation will explain the WBGT project, sensors and components used, installation, costs, suppliers, as well as the data obtained during this summer and how it is used at Y-12. The overall goal is to improve heat stress awareness of the Y-12 plant population, provide Fire Services and Industrial Hygiene with needed heat stress information, and to provide a historical archive of measurable WBGT.