6.7 A COMPARISON OF THE STEDMAN'S HEAT INDEX AND THE WBGT INDEX

Steven D. Hacker and David R. Smith.
U.S. Naval Academy
Annapolis, MD 21402

1. BACKGROUND

Human comfort level is measured in terms of environmental factors. Temperature, humidity, wind, and radiant energy all contribute to how the body feels and responds. Physical activity, such as athletics and military training, often must occur in spite of adverse environmental conditions. In fact, it may be part of the culture of such activities to push the envelope to determine what the human body can do under extreme conditions. Unfortunately, excess heat and moisture can result in physiological stress, perhaps thermal exhaustion or even death. For example, this past summer there were several reports in the media of deaths resulting from overexertion during periods of extreme temperature and humidity levels.

The environment can be monitored to determine when conditions become too dangerous for physical activity. There are several indices that quantify human comfort levels, relating environmental factors to physiological response. Most involve empirical algorithms that are functions of various environmental parameters. Stedman's Heat Index is one of the more common comfort indices. It is a function of temperature and relative humidity. The National Weather Service, among other organizations, routinely report values of the Stedman's Heat Index as guidance for stressful situations. Another index, the Wet Bulb Globe Temperature (WBGT) Index is used by the military to measure environmental factors and then determine an appropriate level of physical training. The WBGT Index is a more complicated formula that utilizes dry-bulb (DB), wet-bulb (WB) and black-globe (BG) temperatures:

$$WBGT = 0.7*WB + 0.2*BG + 0.1*DB.$$

The military has conducted research to correlate WBGT values to heat stress (Minard, Belding and Kingston, 1957).

The United States Naval Academy (USNA) is but one of many military facilities that conduct training during summer months. Conditions in Annapolis, Maryland in July and August can be unbearably hot and humid, with temperatures often exceeding 90 F and relative humidity levels in the 80-100% range. Such conditions would considered dangerous with regard to physical activity, so they must be monitored carefully to guard against heat stress injury.

This study will focus on developing an algorithm to transform from the Wet Bulb Globe Temperature (WBGT) Index to the Stedman's Heat Index. While WBGT may be relatively easy to determine using a simple instrument that measures dry-bulb, wet-bulb, and a radiant temperature which are combined to yield the index, it is somewhat labor intensive. An automated weather observation system currently in place at the United States Naval Academy provides up-to-date Stedman Heat Index values available on the web. The purpose of this month long study will provide the a database to make the transformation between the two indices and apply the same (or closely similar) criteria for physical exertion.

2. METHODOLOGY

As a matter of military procedure, USNA measures WBGT values during summer months. These observations are taken at various locations where physical activity occurs to help determine if the environmental conditions exceed acceptable threshold levels for physical activity.

Corresponding Author: David R. Smith, United States Naval Academy, Oceanography Department, 572M Holloway Road, Annapolis, Maryland, 21402; E-mail - drsmith@usna.edu.

This is a labor-intensive process, which could produce somewhat suspicious results, given the limited amount of training provided to the individuals who take the observations. However, another system exists at USNA, that could greatly facilitate the monitoring process. An Automated Weather Source (AWS) instrument system continuously measures atmospheric conditions and computes the Stedman's Heat Index and reports this data on a website. Advantages of this system is that it is totally automated, measures atmospheric parameters in a fully standardized fashion, calculates the heat index, and reports measurements at a regular interval over the Internet. While this system provides consistent monitoring of environmental conditions readily available on office computers, some problems need to be resolved. First, the AWS system is a mounted instrument system, located at a site somewhat removed from athletic fields. Unfortunately, this mounted system does not afford the portability that the hand-held WBGT monitor provides, which can be taken from site to site to make measurements where physical activity will take place. Secondly, spatial variability can be significant in terms of those variables that contribute to the heat index. One must ask if the observations at the instrument site are representative of conditions at physical training sites. Part of the experimental design of this study was to determine if the spatial variability of environmental conditions lies within acceptable limits. Ultimately, it must be determined if the advantages of ease of making observations in a consistent manner and reported routinely over the Internet outweigh the disadvantages mentioned above.

The first step in this exercise was to compare observations of the AWS system against the WBGT meter. Observations were first taken at the Hendrix Oceanography Laboratory, where the AWS instrument suite is located, using both the hand-held WBGT meter and the AWS system to determine instrument variability. Next, WBGT measurements were taken at two different locations to determine the spatial variability of the environmental conditions and the computed WBGT values. Lastly, the Stedman's Heat Index computed from the automated system will be compared to the WBGT values to determine if there is a relationship that can be expressed in terms of an algorithm so that the current threshold values associated with WBGT measurements can be correlated to Stedman's Heat Index.

3. CONCLUSIONS

Results reported herein are very preliminary. The analysis phase of this project has just begun. By the time this paper is presented, a thorough analysis will be accomplished and more complete results will be presented at that time.

The first step of the project was to make measurements using both instruments at the same location. The location chosen was Hendrix Oceanography Laboratory. The AWS instrument suite is mounted on a pole approximately 5 meters above ground level. The WBGT was hand-held at approximately 1.5 m above the ground. Clearly, there will be some vertical variation in temperature and moisture related variables, however, the purpose of this portion of the project was to determine the instrument variability given the normal conditions under which observations are taken.

Fig. 1 shows a time history of the observations made over a five-day period. On these days, observations were taken simultaneously at the Hendrix Oceanography Laboratory site. Over this observational period, the Stedman's Heat Index (SHI) and the WBGT values were positively correlated with a differential between the two indices ranging from 0.1 to 8.4 EF, and a mean deviation of 2.65 EF over the observation period This graph clearly demonstrates that the two instruments provide consistent observations over this initial period., and a means of comparison between the two heat indices used in this study. Consequently, it is reasonable to assume that one could choose either of the heat indices to develop criteria for heat stress.

The second step was to determine the degree of spatial variability in WBGT values between two different locations. The first location was the Hendrix Oceanography Laboratory. This site is located on the Severn River, consequently temperatures normally run a few degrees cooler than sites more centrally located on the campus, hence further removed

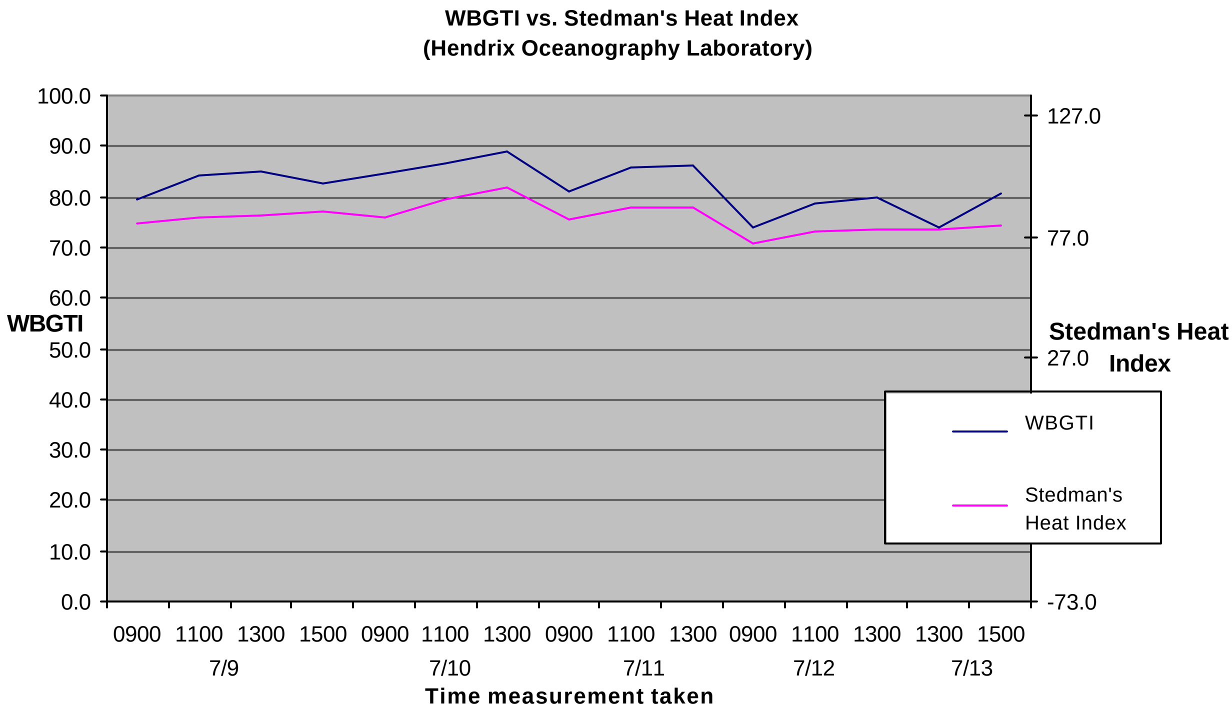

Figure 1. - Comparison of Wet-bulb Globe Temperature (WBGT) Index and Stedman's Heat Index measured at the United States Naval Academy Hendrix Oceanography Laboratory (9-13 July 2001). Both variables are in units of EF.

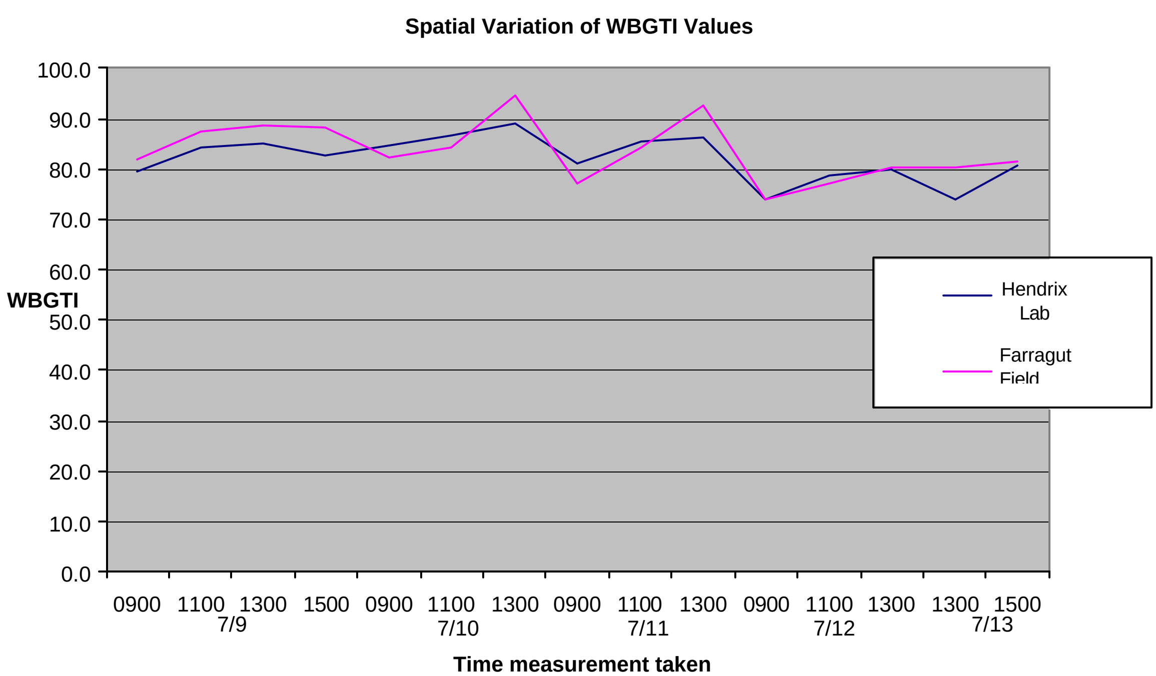

Figure 2. - Comparison of Wet-bulb Globe Temperature (WBGT) Index measured at the Hendrix Oceanography Laboratory and Farragut Field (9-13 July 2001). Both variables are in units of EF.

from the water. In addition, moisture content tends to be slightly higher, resulting in more humid conditions than locations further inland. The second location was at one of the athletic fields, located approximately 500 m SSE from the Hendrix Oceanography Laboratory. This site was approximately 150 m from the water where the Annapolis Harbor opens to the Chesapeake Bay. This location generally is a few degrees warmer, but with comparable humidity than the Hendrix location. Fig. 2 displays a five- day history of WBGT values measured at the two locations. In general, the measurements at both locations are quite comparable. As expected, the values of WBGT at the athletic field tend to be higher than those measured along the water, with a range of deviations from -3.8 to +6.7 deg F and a mean deviation of 3.07 deg F. This suggests that spatial variability may not be so great and that using values measured at the site along the Severn River could very well be representative of conditions for nearby athletic fields.

4. CONCLUSIONS

These preliminary results provide support for the hypothesis that use of Stedman's Heat Index measured with the AWS system, which is mounted at the Hendrix Oceanography Laboratory, is a suitable substitute for the WBGT values currently measured with a hand-held instrument. While the WBGT meter offers the advantage of measurements on-site and heat-stress threshold criteria that has been documented for military training. On the other hand, the margin for error due to inconsistencies in measurement techniques may very well counter the advantage of having on-site measurements. The advantage of the AWS system is that it is automated, provides continuous measurements that are available on the Internet, and, at least preliminarily provides a heat index that is consistent with the WBGT index.

Future plans include examining data over a one-month period to determine if the WBGT values and the Stedman's Heat Index values are positively correlated over a longer duration. The data will be analyzed statistically to determine the degree of correlation between the two indices. In addition, the spatial variability will be evaluated to determine if a single site is representative for the Naval Academy at large. Lastly, the WBGT values and the Stedman's Heat Index values will be analyzed using linear regression to determine if there is an algorithm that can be used to adapt the heat stress threshold criteria to Stedman's Heat Index values. These results will be presented when the conference meets in Jan 2002.

REFERENCES

Minard, D., H.S. Belding, and J.R. Kingston (1957). "Prevention of heat casualities", *Jour. Amer. Med. Assoc*., 165(14), 1813-18.