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Case Studies

Personal Heat Stress Monitoring

Dawn Tharr, Column Editor

Report by John Decker, Alan Echt, Max Kiefer, and Greg Burr

Introduction

The Wet Bulb Globe Temperature Index (WBGT) is the accepted standard method for determining environmental heat stress in industry.⁽¹⁻³⁾ The WBGT combines the effects of humidity, air velocity, air temperature, and radiant heat into a single measurement. Individual metabolic heat production rates must be estimated and combined with the work-rest regimen for the task(s) being monitored to determine the appropriate heat stress exposure limit. The measured WBGT and estimated metabolic heat production rates can be used to determine the work-rest regimen necessary to avoid exceeding the National Institute for Occupational Safety and Health (NIOSH) Recommended Exposure Limit (REL). These evaluation criteria have been established to prevent exposed workers from exceeding a deep-body or core temperature of 100.4°F (38°C). The consensus among work physiologists and standard-setting organizations is that this temperature is the value below which the body temperature must be maintained to reduce the risk of heat-induced illness.⁽¹⁻⁴⁾

As an evaluation technique, the WBGT method is at best only an imprecise indicator of the heat load experienced by a worker. Assumptions must be made regarding the worker's degree of acclimatization and physical fitness. The REL must be adjusted for weight and clothing. Work rates and metabolic heat production must be estimated. Errors in estimating metabolic rates from energy expenditure tables have been reported to be as high as 30 percent.⁽⁵⁾ In addition, these heat stress indices may not be

appropriate for situations where clothing that inhibits or prevents evaporative heat loss (e.g., personal protective equipment) is worn.

Direct measurements of core body temperature typically entail unacceptably invasive techniques (rectal temperature) or require strictly controlled procedures (oral temperature).⁽⁶⁾ Commercially available personal heat stress monitors have been developed that are capable of monitoring workers on a continuous basis through a variety of techniques (skin temperature, ear canal temperature, and heart rate). These monitors generally offer data-logging capability and alarm functions for alerting workers when preset limits are exceeded. It should be noted that the accuracy and precision of these monitors have not been evaluated by NIOSH.

In conjunction with four separate heat stress investigations, NIOSH industrial hygienists conducted a limited evaluation of one type of personal heat stress monitor that utilized the ear canal temperature technique. The following case reports summarize the investigators' findings, observations, and conclusions regarding these monitors.

Monitor Description

In order to determine indoor WBGT levels, area heat stress monitoring was conducted with Reuter-Stokes 214 WiBGeT[®] monitors (Imaging and Sensing Technology Canada Inc., Cambridge, Ontario, Canada). These units were placed as close as possible to the workers and in a manner that did not restrict free air flow around the thermometer bulbs. The wick of the wet-bulb thermometer reservoir was moistened with demineralized water and the thermometer reservoir filled prior to sampling. The monitors were allowed to equilibrate in each area

evaluated for at least 5 minutes prior to recording readings. The monitors were operated in the automatic data-logging mode and were programmed to record the measured parameters (dry bulb, wet bulb, and globe temperature) at 5-minute intervals. Metabolic heat production rates in kilocalories per hour (kcal/h) were estimated by observing body position and work activities and by referencing standard tables.⁽²⁾

Personal heat stress monitoring was conducted using a QuesTemp[®] II[®] (Quest Electronics, Oconomowoc, Wisconsin). This device assesses body temperature via the ear canal. The difference between the ear and body temperatures are compensated for by calibrating the unit directly to the worker's oral temperature. A small sensor, which is placed in the ear canal via an earplug, monitors changes in the body's temperature and will alarm the worker if the level exceeds a preset limit [factory set at 100.4°F (38°C), adjustable up to 102.2°F (39°C)]. The monitor also continuously logs body temperature for subsequent evaluation, such as assessing the heat stress incurred from specific tasks. The ear mold containing the plug and sensor is equipped with both a secondary temperature sensor that monitors the worker's environment and a small speaker used for an audible alert. It should be noted that the secondary sensor provides only an estimate of ambient temperature because the values may be affected by its proximity to the worker's head.

Case 1

Background

On September 11, 1991, NIOSH conducted a heat stress evaluation at a textile dyeing, printing, and finishing facility in Georgia.⁽⁶⁾ Using raw greige

(unbleached, undyed material), the facility produced home furnishings and Japanese apparel cloth.

Evaluation Methods

Personal heat stress monitoring, using a QuesTemp[®] II monitor, was conducted on an employee who was assigned to work on a rotary printer. A WiBGet[®] WBGT monitor was placed in the work area.

The employee worked a 12-hour shift with one 10-minute and two 20-minute breaks. The break room was air-conditioned. The employee's clothing consisted of a single-layer, short-sleeve cotton shirt and jeans. His weight was approximately 150 pounds. He had spent 12 years on the job and was considered to be acclimatized. Heat stress monitoring was conducted between 8:24 A.M. and 3:50 P.M.

The rotary printer was adjacent to a soil-resist applicator machine which generated heat and steam that affected workers in the printer area. Pedestal fans were present at each side of the rotary printer. No breaks were provided for the purpose of heat relief. Although no heavy lifting was involved in the task, considerable body movement was necessary. The work was considered by NIOSH investigators to be continuous, involving the whole body, and in the moderate category. The worker indicated that the tasks evaluated were consistent with a normal workday. Based on Table V-3 of the NIOSH *Occupational Exposures to Hot Environments, Revised Criteria, 1986*⁽⁶⁾, the worker's energy expenditure was estimated to be about 6.6 kcal/min (400 kcal/h), a level which equates to a REL of approximately 80°F (26.5°C) WBGT for continuous work.

Results and Discussion

The results of the area (WBGT) and personal heat stress monitoring (QuesTemp[®] II, ear/core body temperature) are shown in Figure 1. The WBGT increased throughout the day and exceeded the calculated REL of 80°F (26.5°C) for continuous work. The core body temperature exceeded the recommended limit of 100.4°F (38°C) at

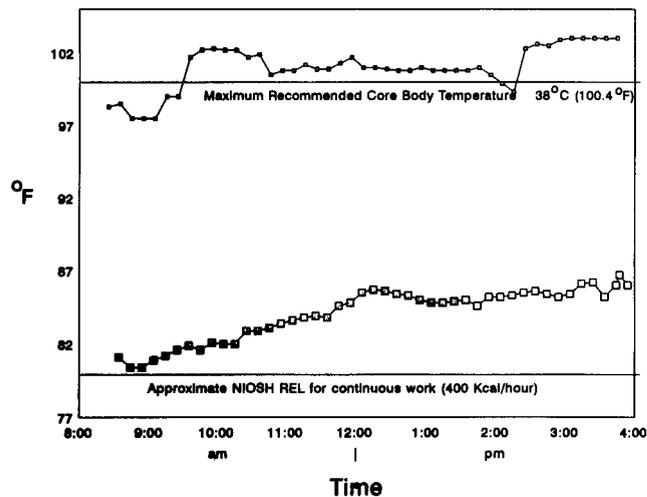


FIGURE 1. Textile finishing facility: textile printer operator. Key: \circ = ear temperature; \square = WBGT.

9:35 A.M. Decreases in core body temperature occurred when the employee was on break (around 10:45 A.M. and 2:00 P.M.).

Area measurements at three locations in the plant indicated that heat stress exposures were in excess of NIOSH and the American Conference of Governmental Industrial Hygienists (ACGIH) recommendations. In addition, the QuesTemp[®] II core body temperature exceeded the recommended maximum of 100.4°F (38°C) for most of the day, indicating that a heat stress hazard existed. Thus, the personal heat stress measurements agreed with the WBGT results.

Case 2

Background

This NIOSH survey was conducted at a company that produced aircraft fuel cells and portable storage tanks from rubber-coated fabrics.⁽⁷⁾ Approximately 600 people were employed at two plants. The evaluation concerned numerous chemical exposures throughout the plant. The investigation also examined a variety of alleged health effects resulting from the manufacture of coated rubber fuel cells, including heat stress.

The fuel cells (primarily used in military aircraft) composed the largest segment of production at this facility and ranged in capacity from several hundred to several thousand gallons.

Since the fuel cells were designed to fill all available interior space in an aircraft, the shapes were complex. While some of the fuel cells had a small capacity (permitting both exterior and interior surfaces to be cleaned easily), the larger-capacity fuel cells required the employees to enter the empty cell completely to perform the final cleaning and inspection of all the interior surfaces.

During final cleaning, small hand tools, sandpaper, and rags were used to remove excess glue, paper, and plaster from the interior surfaces. The interior was also cleaned with a solvent (1,1,1-trichloroethane) by the employees while inside the cell. The employees were required to wear half-mask, air-purifying respirators equipped with organic vapor cartridges when working inside the fuel cells with solvent. No special protective clothing was required (the workers' clothing typically consisted of a tee shirt and jeans). NIOSH investigators estimated that a moderate level of exertion (using both arms) was required when working inside a cell (an area that met the NIOSH definition of a confined space). The work was considered continuous, and employees were assumed to be acclimatized because they worked in the final cleaning department on a consistent basis. The cleaning and inspection process could take two workers over 2 days to complete.

It was during the cleaning and in-

spection of a large fuel cell on August 20, 1991, that the WBGT and personal heat dosimetry measurements were made. Like the majority of the plant, the final cleaning department was not air-conditioned. Untempered air was blown into the occupied fuel cells both to cool the workers and to dilute the airborne solvent concentration. The dilution air was provided by portable electric blowers situated on the floor outside the cell. Overhead propeller fans (mounted perpendicular to the ceiling) were used to circulate the air during the day.

Evaluation Methods

One of the two women assigned to clean and inspect a large-capacity fuel cell was fitted with a QuesTemp[®] II prior to entering the cell. A WBGT meter was mounted on a tripod and positioned inside the fuel cell during the approximately 3-hour sampling period while the women performed their work. The sampling period ended when both women left the fuel cell to go on a scheduled break.

Results and Discussion

Dry bulb and WBGT temperatures ranged from 89° to 96°F and from 78° to 81°F respectively, inside the fuel cell. The personal monitoring indicates that the worker's core body temperature did not reach 38°C at any time during the sampling period. As shown in Figure 2, the relatively constant WBGT

levels measured within the fuel cell correlated with the worker's personal temperature. The NIOSH heat stress REL for this cleaning task was estimated based on a moderate level of exertion involving the entire body.

Case 3

Background

On September 25–26, 1991, NIOSH investigators conducted a heat stress evaluation at a wholesale bakery in Louisiana.⁽⁸⁾

Evaluation Methods

Personal heat stress monitoring was conducted on the "Jet-Oven" operator. Employees felt that this job was the hottest. Concurrent area monitoring, using the WiBGeT[®], was conducted for this job.

The Jet-Oven (an indirect-fired heater that operates at a temperature of 350°–425°F) line was a continuous, conveyor-driven baking operation. The operator was responsible for setting up the line, ensuring that the product entered and exited the oven properly, and maintaining a clean area. Rapid movement and exertion were periodically required when problems occurred (e.g., failure of bread to separate from pans, conveyor problems).

The employee monitored was a 42-year-old, 165-pound male. The employee had worked in this depart-

ment for several years and was considered to be heat-acclimatized fully. He wore a light cotton shirt and pants and a hairnet. The employee swept around the Jet-Oven for the first 45 minutes of the sampling period. The remainder of the workshift consisted of monitoring the product. Energy costs, estimated by task analysis, indicated an energy expenditure of approximately 300 kcal/h for this activity. Because the work was continuous (no work-rest regimen), a REL of 82°F (28°C) WBGT was assigned for this task.

Results and Discussion

The personal and area monitoring results are shown in Figure 3. The QuesTemp[®] II monitor's alarm activated (indicating a core temperature exceeding 38°C) very soon after the employee arrived at his work station (approximately 1:20 PM). The alarm continued to activate periodically, even though the employee's work-rate and the ambient WBGT monitoring did not indicate that high heat stress conditions existed. At 2:30 P.M., the unit was recalibrated, and a difference of -3.7°C between the employee's original oral-ear temperature measurement and the new calibration measurement was noted. Quest technical representatives were consulted to determine why the alarm activated and to discuss the necessity for recalibration. Quest representatives theorized that because the initial dosimeter calibration occurred in an air-conditioned office environment, there was inadequate stabilization of the temperature sensors in the work area. For this reason, the first 80 minutes of monitoring data were invalid and, therefore, are not presented in Figure 3.

The monitoring indicated that the worker's core body temperature did not reach 38°C at any time during the sampling period. The highest recording was 37.5°C at 3:51 PM. The worker's activity was light during the sampling period; however, there were a few instances when exertion was necessary. Therefore, metabolic heat production by the worker monitored was low dur-

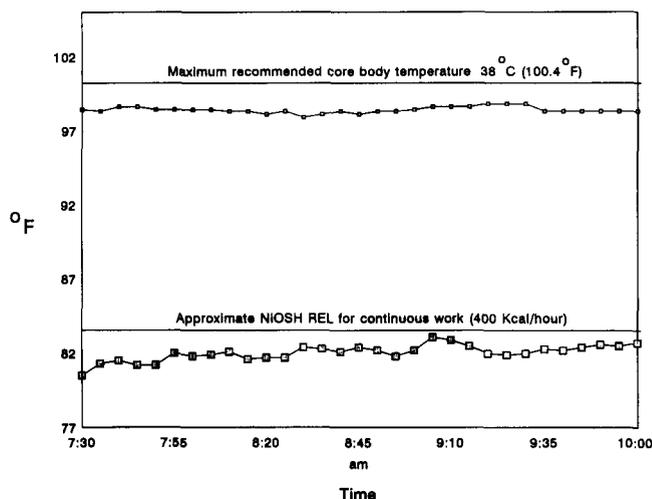


FIGURE 2. Fuel cell manufacturer: fuel cell final finish. Key: \circ = ear temperature; \square = WBGT.

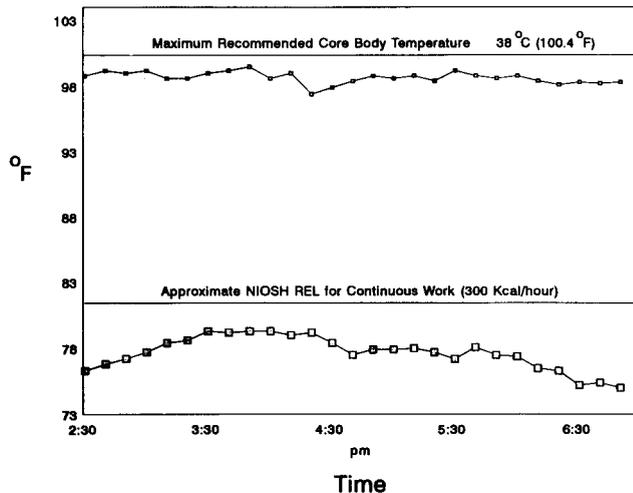


FIGURE 3. Wholesale bakery: jet oven operator. Key: \circ = ear temperature; \square = WBGT.

ing the sampling period. Similarly, the WBGT evaluation did not indicate that an exposure to excessive environmental heat had occurred.

The environment in the production area of the bakery was affected by outside climatic conditions (air-conditioning was not provided and extensive outside make-up air was required to compensate for the oven heat exhaust). On the day monitoring was conducted, however, outside conditions were optimal (mild temperature, low humidity). Therefore, the monitoring was not considered to be representative of conditions that would be present during the hotter months of the year. Additionally, the effect of higher metabolic heat production rates during periods when considerable exertion was necessary (e.g., machine problems requiring manual handling of product) could not be determined.

The worker's acceptance of the personal dosimeter was good. Although hearing protection is not normally worn by employees, the worker did not indicate any discomfort with the device.

Case 4

Background

On January 14–16, 1991, NIOSH investigators conducted an initial survey at a university to evaluate heat stress among employees assigned to work in the steam tunnels.⁽⁹⁾ On August 29–30,

1991, additional heat stress measurements were conducted in order to evaluate environmental conditions in the summer months.

The approximately 5.5 miles of steam tunnels at this university provided steam for a variety of uses, including steam tables in food service facilities, steam sterilizers in the hospital, and steam heat in buildings. Thirteen employees were available for work assignments in the steam tunnels. These work activities included various maintenance and repair tasks necessary to provide steam service to university facilities. Most of the work performed in the tunnel included inspecting and cleaning the tunnels, lubricating expansion joints, and repacking valves.

Employees are allowed to work at their own pace and take breaks when they judge it to be necessary. Tunnel workers use the buddy system, some heat stress training is provided, and a medical surveillance program has been initiated recently. Circulating-liquid cooling vests are available for the hottest jobs. Maintenance trucks are equipped with Botsballs™ and coolers of Gatorade™.

Evaluation Methods

On August 30, 1991, WBGT and personal dosimetry measurements were obtained for three tasks in three different portions of the tunnel: repacking a valve, replacing a union, and installing a blowoff. The valve repacking opera-

tion was stopped when a problem was noted that made repacking unsafe. Metabolic heat produced during the remaining operations was estimated using the guidelines provided in the NIOSH *Occupational Exposure to Hot Environments, Revised Criteria 1986*.⁽¹⁾ Because of the inherent uncertainty of estimating metabolic heat production, a range of estimated values was determined, using the high and low values from the table of metabolic heat production rates in the revised criteria document.⁽¹⁾ The WBGeT was mounted on a tripod near the worker. The Questemp° II was calibrated in the tunnel at the beginning of each task. Employees were assumed to be acclimatized because they were steamfitters assigned to tunnel work and because the site visit occurred at the end of the summer.

Results

The 1-hour time-weighted average (TWA) WBGT for installing a steam blowoff was 90.8°F. The estimated 1-hour TWA metabolic heat produced during this activity ranged from 120 to 138 kcal/h. Completion of this task took about 20 minutes. The remaining 40 minutes used to calculate the 1-hour TWA was spent exiting the tunnel, resting, and returning to the physical plant complex. The 1-hour TWA WBGT for replacing a union was 84.7°F. The 1-hour TWA estimates of metabolic heat produced during this activity ranged from 144 to 162 kcal/h. This task was completed in 15 minutes, followed by a 40-minute rest period, and 5 minutes spent preparing for and walking to the next job. Neither of these tasks resulted in heat stress measures in excess of the recommended exposure limits for acclimatized workers. Aural temperatures measured during these two tasks confirmed this. The mean aural temperature measured during the installation of the steam blowoff was 98.7°F, while the mean aural temperature measured during the replacement of a union was 98.5°F. However, NIOSH investigators concluded that tasks which exposed employees to these hot environments for longer periods of time

would place the employees at risk of heat stress.

Conclusions

1. The use of personal heat stress monitors is one method for overcoming the inherent problems of extrapolating WBGT area readings and metabolic heat production estimates. The effect of confounding factors (degree of physical fitness, acclimatization, age, sex, weight, alcohol intake, clothing) are compensated for by indirect measurements of an individual's core temperature.
2. Personal heat stress monitors could be effectively applied to characterize an individual worker's ability to function in hot environments and the relative heat stress of specific tasks, and for situations where WBGT monitoring is not applicable (e.g., emergency response/hazardous waste activities where vapor-impermeable clothing is worn).
3. A detailed assessment of the variability and accuracy of this type of monitor is necessary. Because the ear plug may not be inserted the same way for each use, the effect of different degrees of fit needs to be investigated. The variation in temperature differentials (oral, rectal, ear) should be fully evaluated because the monitor assumes these to be constant.
4. Heat stress monitoring should be a

component of an overall heat stress program. Worker training, fluid replenishment, acclimatization, work-rest regimens, medical screening, and heat alert programs are all essential elements of a good heat stress management program.

5. Ease of use, absence of discomfort, and worker acceptance of the monitor were good.
6. The monitor manufacturer should consider developing sensors with other types of aural inserts. This would be especially useful in areas where hearing protection is required and a variety of hearing protectors are used. The effect on the noise reduction rating of the hearing protector would need to be determined for each device.
7. The monitor should always be calibrated in the environment to be evaluated.

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