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13. ABSTRACT (Maximum 200 words) Temperature offsets to the wet bulb, globe temperature index (WBGT), used to provide guidance for work/rest cycles and fluid replacement for Soldiers in the field wearing standard military uniforms, were developed for increased heat stress wearing protective equipment. This report details how those offsets were determined, and shows the basis for the revised offsets in the current TBMED 507. A computer simulation (USARIEM-EXP) was used to calculate core temperatures in a Soldier wearing the Hot Weather BDU, MOPP 1, and MOPP 4 at a WBGT temperature of 86°F, at two work intensities. Core temperature responses at lower WBGT temperatures were then simulated until the core temperature for Soldiers in MOPP 4 was equivalent to that in the BDU at WBGT 86°F. Similar comparisons were made for soldiers wearing the BDU with body armor in compensable and uncompensable hot environments. Findings indicate that compared to wearing only the BDU, WBGT temperatures should be offset by: (1) + 10°F at light work in MOPP 4, (2) + 20°F at moderate work in MOPP 4, (3) no adjustment if skin is dry in body armor with the BDU, and (4) + 5°F if skin is wet in body armor with the BDU.				
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USARIEM TECHNICAL REPORT TN05-04

**WBGT INDEX TEMPERATURE ADJUSTMENTS FOR WORK/REST CYCLES WHEN
WEARING NBC PROTECTIVE CLOTHING OR BODY ARMOR**

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EXECUTIVE SUMMARY

The wet bulb, globe temperature index (WBGT) is commonly used by the military to determine heat stress categories (1-5, from least to most severe) for Soldiers in the field. These heat stress categories are used to provide guidance for work/rest cycles and fluid replacement. The WBGT index is derived by considering the impact of ambient or dry bulb (T_{db}) temperature; wind and humidity, as measured by the wet bulb temperature (T_{wb}); and radiant heat, as measured by the black globe temperature (T_{bg}). The formula for calculating the outdoor WBGT is $WBGT = 0.7 (T_{wb}) + 0.2 (T_{bg}) + 0.1 (T_{db})$. This index was derived for military troops wearing standard battle dress uniforms (BDU). Since its inception, temperature offsets have been developed for the increased level of heat stress added by wearing extra levels of protective equipment. Up until the 2003 revision of TBMED 507 (18), these offsets were +10°F for nuclear, biological, and chemical (NBC) clothing, and +5°F for body armor. This report will provide a historical background on how those offsets were determined, and show the basis for the revised offsets used in the current TBMED 507.

The impact of wearing either NBC protective clothing or body armor was tested using a computer simulation (USARIEM-EXP) to estimate core temperature responses in specific environments. Inputs into the USARIEM-EXP include environmental factors of ambient temperature, humidity, wind speed, solar load, and clothing parameters, as well as personnel factors of height, weight, exercise intensity, days of heat acclimation, and hydration level. The model output includes such items as work/rest cycles, fluid requirements, final equilibrium core temperature, and a core temperature response curve across time. The USARIEM-EXP was used to simulate a soldier wearing each of three uniform configurations (Hot Weather BDU, MOPP 1, and MOPP 4) at a WBGT index temperature of 86°F (30°C). This is representative of military Heat Category 3. Simulations were conducted at light (250 W) and moderate (425 W) work intensities. Once these equilibrium core temperatures were established, the USARIEM-EXP was used to simulate equilibrium core temperatures at sequentially lower WBGT index temperatures until the equilibrium core temperature for Soldiers in the MOPP 4 configuration was equivalent to that in the BDU at WBGT 86°F. This resulted in a determination of the appropriate temperature offset from standard WBGT index guidelines when wearing MOPP 4.

Similar comparisons were also made between measured core temperature responses during moderate continuous work while wearing the BDU and body armor in a hot environment that allowed evaporative cooling and a simulation of the same parameters without the armor. Simulated core temperature responses were additionally calculated for Soldiers performing light and moderate continuous work wearing either the BDU or BDU and body armor in environments that restrict evaporative cooling.

During continuous light work, it requires approximately a 10°F decrease in the WBGT index temperature for the simulated equilibrium core temperature of individuals wearing MOPP 4 to be the same as in BDU or MOPP 1. During continuous moderate work, a 20°F decrease in the WBGT index temperature is required for the simulated equilibrium core temperature of individuals clothed in MOPP 4 to be the same as in BDU or MOPP 1. There is no difference in equilibrium core temperatures with or without body armor over the BDU for Soldiers engaged in moderate continuous work in environments allowing evaporative cooling. Once evaporative cooling is limited, the WBGT index temperature must be lowered 5°F for Soldiers wearing body armor for equilibrium core temperature to be the same as in the BDU with no armor.

The findings of these analyses indicate that WBGT index temperatures should be corrected by the following offsets: (1) +10°F at light work when wearing MOPP 4, (2) +20°F at moderate work when wearing MOPP 4, (3) no adjustment if skin is dry when wearing body armor with the BDU, and (4) +5°F if skin is wet when wearing body armor with the BDU.

INTRODUCTION

Beginning in 1953, the U.S. Marine Corps Recruit Depot at Parris Island, S.C., modified its hot weather training policy during “periods of moderate to severe climatic heat” (14). These modifications included such things as emphasizing liberal water intake, adapting dress to the environment, and curtailing or reducing physical activity relative to the environmental conditions. A method to easily determine the severity of environmental stress by units in the field became part of the effort to reduce the incidence of heat strain casualties at Parris Island. At that time, there were indices that could be used to derive the heat strain created by the environment. Examples are the Corrected Effective Temperature Index, the Effective Temperature including Radiation, and the Heat Stress Index (1, 13). These indices all included factors of ambient temperature, humidity, solar load, and wind speed, and some included the impact of physiological variables such as energy expenditure and skin temperature. All of the indices, however, required complex equipment and trained technicians to collect data (1, 13). A more simplified measurement tool was required for use by the military in a field environment. In 1954, the wet bulb, globe temperature (WBGT) index was tested at three Marine Corps Training Centers as such a tool for measuring the local heat stress in a training area (19). The WBGT index was found to be an accurate assessment of the level of heat stress when compared with other more complex indices (13), and was adopted for use by the military.

The WBGT index is now commonly used by the military to determine heat stress categories for soldiers during warm weather training. Table 1 shows the current example of the categories as presented in the latest version of TBMED 507 (18). These categories (from 1-5, least to most stressful) are used to provide guidance for work/rest cycles and fluid replacement. The WBGT index is derived by considering the impact of ambient or dry bulb (T_{db}) temperature; wind and humidity, as measured by the wet bulb temperature (T_{wb}); and radiant heat, as measured by the black globe temperature (T_{bg}). The formula for calculating the outdoor WBGT is $WBGT = 0.7 (T_{wb}) + 0.2 (T_{bg}) + 0.1 (T_{db})$. This index was derived for military troops wearing standard battle dress uniforms (BDU). The WBGT index is traditionally expressed in the Fahrenheit scale. Throughout the years since its inception, temperature offsets have been developed for the increased level of heat stress added by wearing extra levels of protective equipment. Up until the current version of TBMED 507 (18), these offsets were +10°F (5.6°C) for nuclear, biological, and chemical (NBC) clothing, and +5°F (2.8°C) for body armor. This report will provide a historical background on how those offsets were determined, and show the basis for the revised offsets used in the current TBMED 507.

An intensive development program was begun in 1960 to improve NBC protective uniforms in response to ongoing threats of chemical and biological warfare agents in the post World War II era (3). Improved NBC clothing efficacy to protect from toxic agents was achieved by limiting liquid and vapor

permeability, which both insulates the soldier and reduces evaporative cooling. Both controlled environmental chamber and field exercise studies were conducted by Goldman (6, 7) shortly after the development of the NBC protective uniforms in the early 1960s. These initial studies indicated that heat storage in the protective clothing limited tolerance time to approximately 30 minutes at dry bulb temperatures above 75°F (23.9°C) in men performing moderately heavy exercise (walking at 3.75 mph on a level track).

Joyce and Goldman derived a theoretical calculation of predicted time to 50% unit heat casualties based on reaching a core temperature of 39.5°C, from data collected in the 1963 field study of Soldiers completing simulated field missions (12). The resultant graph (Figure 1), developed from both field data and data from previous studies, predicted 50% unit survival time (able to continue exercise) when wearing NBC protective uniforms at light (~230 W), moderate (~300 W), and hard (~350 W) exercise levels. This graph showed the impact of the calculated WBGT index temperature on survival time. The survival times shown in this figure were based on a combination of Soldiers' symptoms of heat strain (e.g., nausea, vomiting, abdominal cramp, inability to continue exercise), or removal from the study without reported symptoms, but for having attained a core temperature of 39.5°C (103.1°F). As can be seen from Figure 1, Soldiers dressed in NBC clothing and performing work at 350 W (currently accepted as moderate, not hard work) would be limited to less than 90 minutes of work at a WBGT of 60°F (15.6°C), and less than 1 hr once the WBGT reaches 70°F (21.1°C). The basic determination of the study was that at a WBGT of 80°F (26.7°C) or greater, the impact of NBC clothing made it nearly impossible to complete tactical tasks that involved work at 350 W for more than 1 hr. It was further concluded that some tasks could be completed at WBGT index temperatures between 60°-80°F (15.6°-26.7°C), although some individuals would still become heat casualties (12).

The theoretical calculations devised by Joy and Goldman in their 1968 report resulted in the conclusion that when NBC clothing was worn in closed or Mission Oriented Protective Posture Level 4 (MOPP 4), all work times should be reduced by 1/3 relative to open or Mission Oriented Protective Posture Level 1 (MOPP 1), with NBC clothing worn open at the neck, and no mask, protective hood, or gloves (12). By 1973, the recommendations to protect individuals working in NBC clothing had been altered to state that the WBGT index temperature at which an individual dressed in MOPP 4 could be expected to safely perform work should be reduced 5.4-9.0°F (3°-5°C) (8). For example, if it was expected that 50% of men would reach physiologic tolerance limits in approximately 100 minutes at a WBGT of 95°F (35°C) while performing moderate work dressed in light clothing, it was proposed that their responses would be the same at 86°-89.6°F (30°-32°C) when wearing protective clothing at MOPP 4. In a paper presented to the Commonwealth Defense Conference on Operational Clothing and Combat Equipment in 1981 (10), Goldman reported that for Soldiers performing moderate work, "little problem would be anticipated with WBGT in the

70°F (21.1°C) range for closed suit, or below 80°F (26.7°C) for open suit.” This 10°F (5.6°C) difference between open and closed protective clothing became ingrained in the U.S. Army doctrine as the safety limit for performing work while wearing NBC clothing in the MOPP 4 configuration.

A December 1980 position paper from the National Institute for Occupational Safety and Health (9) also included the recommendation that the WBGT index criterion for risk of heat exposure be reduced by 10°F (5.6°C) when individuals were wearing protective clothing. The Occupational Safety and Health Administration (OSHA) Technical Manual (15), last updated in 1995, extended that guidance to recommend that the Threshold Limit Values for workers wearing permeable, water barrier clothing be reduced by ~11°F (~6°C) relative to wearing summer lightweight work clothes.

More recently, Reneau and Bishop (17) observed that when men performed identical work dressed in standard fatigues at a WBGT of 86°F (30°C), or dressed in NBC clothing at a WBGT of 68°F (20°C), changes in core temperature and mean heart rate responses were nearly identical. While performed with only five subjects, this limited experiment inspired our research team to re-examine the impact of wearing NBC clothing in both open (MOPP 1) and closed (MOPP 4) configurations on core temperature responses relative to wearing a standard Hot Weather BDU at identical exercise intensities at a given WBGT index temperature. We additionally decided to re-examine the impact on core temperature of Soldiers exercising at a given exercise intensity when adding body armor to the BDU.

The bulk of the information presented in this technical note was derived through use of a validated mathematical model (USARIEM-EXP) that simulates core temperature responses to predetermined clothing, exercise, and environmental parameters (2). The simulations provided data to ascertain the appropriate WBGT index temperature offsets when Soldiers wear NBC clothing in lieu of the standard BDU, or when Soldiers add body armor to their uniform configuration.

Table 1. Fluid replacement and work/rest guidelines for warm weather training conditions. (Applies to average size and heat-acclimatized soldier wearing BDU, hot weather.) (Reprinted from TBMED 507 [18])

Heat Category	WBGT ^{6,7} Index (°F)	Easy Work (250 W)		Moderate Work (425 W)		Hard Work (600 W)	
		Work/Rest ^{1,3}	Water Intake ^{4,5} (qt/hr)	Work/Rest	Water Intake (qt/hr)	Work/Rest	Water Intake (qt/hr)
1	78 – 81.9	No Limit (NL) ²	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
		Easy Work		Moderate Work		Hard Work	
		• Weapon maintenance • Walking hard surface at 2.5 mph, <30 lb load • Manual of arms training • Marksmanship • Drill and ceremony		• 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, 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	

Notes:

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 ($\pm \frac{1}{4}$ qt/hr) and exposure to full sun or full shade ($\pm \frac{1}{4}$ qt/hr).
2. NL equals no limit to work time per hour (up to 4 continuous hours).
3. Rest means minimal physical activity (sitting or standing), accomplished in shade, if possible.
4. CAUTION: Hourly fluid intake should not exceed 1½ quart.
5. Daily fluid intake should not exceed 12 quarts.
6. If wearing body armor, add 5°F to WBGT index in humid climates.
7. If wearing NBC clothing (MOPP 4), add 10°F to WBGT index for easy work, and 20°F to WBGT index for moderate and hard work.

Figure 1. Predicted time to 50% unit heat casualties, as approximated by Joy and Goldman. (Reprinted from Military Medicine: International Journal of ASMUS, 1968. [12])

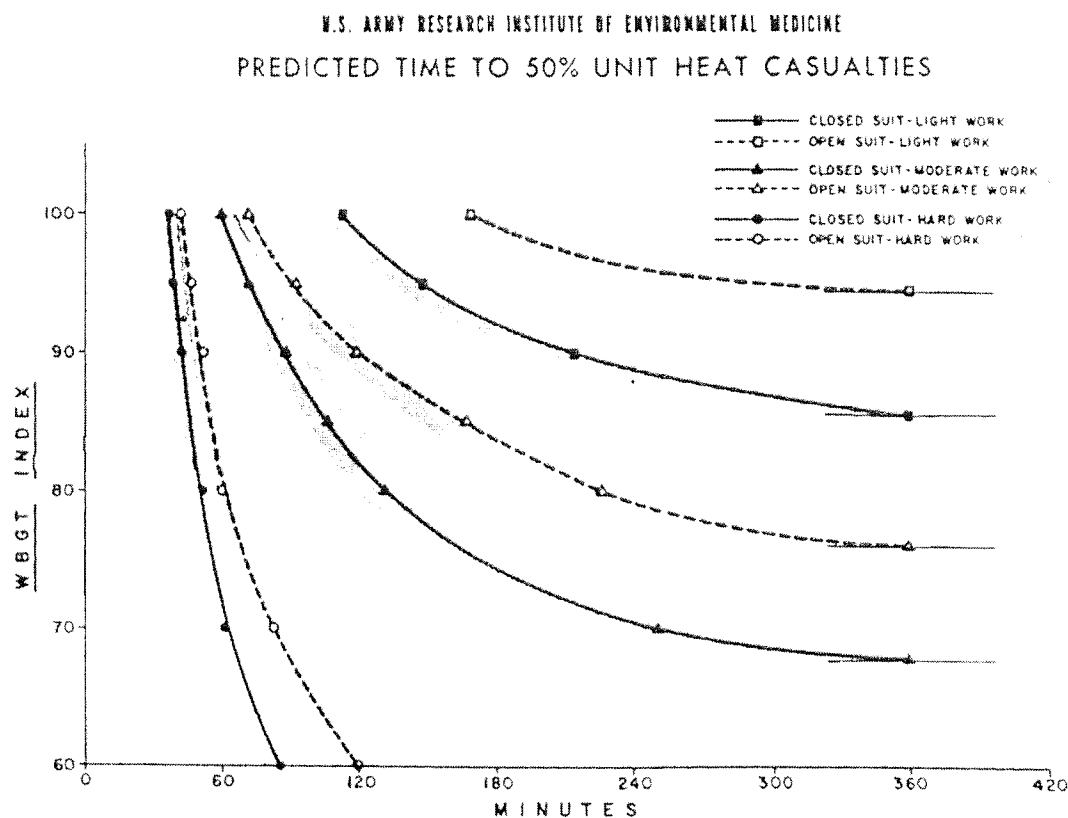


Fig. 12. Prediction graph for 50 per cent unit survival time for CB protective uniforms with reduced water vapor permeability. "Light work" is 200 KCal/hr., and "hard work" is 300 KCal/hr. This graph was developed following the approaches suggested by Blockley, McCutchen and Taylor ("Predictions of human tolerance for heat in aircraft," WADC Tech. Rpt. 53-346, Wright Air Dev. Center, Ohio, May, 1954) and Woodcock (Moisture transfer in textile systems, Textile Res. J., 32, 628, 1962).

METHODS

The impact of wearing either NBC protective clothing or body armor was tested using a computer simulation to estimate core temperature responses of Soldiers exercising in specific environments. The model used for these simulations was the USARIEM-EXP. Inputs into the USARIEM-EXP include environmental factors of ambient temperature, humidity, wind speed, solar load, and clothing parameters, as well as personnel factors of height, weight, exercise intensity, days of acclimation, and hydration level. The model output includes such items as work/rest cycles, fluid requirements, final equilibrium core temperature, and a core temperature response curve across time to the equilibrium temperature. The USARIEM-EXP model, as modified by Gonzalez et al. (11), includes a proportionality control coefficient to buffer the abrupt rise in rectal temperature, which is an unrealistic outcome of the equations used in the standard USARIEM model. This change does not alter the final steady state

equilibrium core temperature as calculated by the original Givoni and Goldman equations (4, 5), but simply reduces the rate of rise in the early portion of the curve. The USARIEM-EXP was one of the simulations used in a validation of multiple versions of the USARIEM model versus human experimental data, and proved the most accurate at tracking the course of human core temperature data across time (2).

NBC CLOTHING

The USARIEM-EXP was initially used to simulate the equilibrium core temperatures and to plot the response curves at a WBGT index temperature of 86°F (30°C) in Soldiers working at both light and moderate intensity while wearing the BDU, MOPP 1, or MOPP 4. Current WBGT index guidelines for continuous work duration for Soldiers dressed in the BDU indicate that this temperature represents Heat Category 3, and that Soldiers should be able to perform light work indefinitely, and moderate level work with 40/20 minute work/rest cycles (Table 1).

Equilibrium core temperatures were obtained using simulations conducted at light (250 W) and moderate (425 W) work intensities at WBGT 86°F, with wind speeds of both 2.2 and 4.5 mph. The 86°F WBGT was calculated using both desert (109.4°F [43°C], 20% rh) and tropic (95°F [35°C], 58% rh) environments to evaluate whether core temperature responses would differ. Variations in humidity appear to have a greater impact than variations in solar load on physiological responses at the same WBGT index temperature when Soldiers are dressed only in the BDU (16). Additionally, the insulation provided by NBC clothing buffers the impact of sunlight, so simulations were performed with no solar load. Once the equilibrium core temperatures for each uniform configuration were established with these parameters, the USARIEM-EXP was used to simulate equilibrium core temperatures at sequentially lower WBGT index temperatures, starting at a WBGT 10°F less than the initial 86°F, until the equilibrium core temperature in the MOPP 4 configuration was equivalent to that in the BDU at WBGT 86°F. This resulted in a determination of the appropriate offset from standard WBGT index guidelines for Soldiers wearing MOPP 4.

BODY ARMOR

The current assessment in TBMED 507 (18) on the heat stress impact of wearing body armor is that the WBGT index temperature should be increased 5°F. To verify the impact of body armor on core temperature responses in exercising Soldiers, data were gleaned from a heat stress study conducted on men wearing body armor over the BDU in two environments favorable for evaporative cooling. The study was conducted at 104°F (40°C), 20% rh, WBGT 82°F (27.8°C), with 2.2 and 5.6 mph wind speeds, and no solar load. The work rate was 425 W. The USARIEM-EXP was used to simulate core temperature responses in the same environments and work rate for men wearing only the

BDU, as there were no experimental data at these conditions. The USARIEM-EXP was additionally used to simulate core temperature responses for men wearing the BDU with and without body armor in four uncompensable heat stress environments all with high ambient temperature and high rh allowing minimal evaporative cooling.

RESULTS

NBC CLOTHING

Tables 2-5 show the simulated equilibrium core temperatures at four calculated WBGT index temperatures for continuous light and moderate work in three uniform configurations at two wind speeds. Tables 2 and 4 show that when Soldiers perform continuous light work at two wind speeds, it requires a 10°F drop in the WBGT index temperature for the equilibrium core temperature in MOPP 4 to be equivalent to the equilibrium core temperatures in MOPP 1 or the BDU. Tables 3 and 5 show that when Soldiers perform continuous moderate work at two wind speeds, it requires a 20°F drop in the WBGT index temperature for the equilibrium core temperature in MOPP 4 to be equivalent to the equilibrium core temperatures in MOPP 1 or the BDU.

Figures 2-5 provide a graphic presentation of simulated core temperature responses across time when Soldiers perform 300 minutes of continuous work in the BDU, MOPP 1, and MOPP 4 in the WBGT index environments represented in Tables 2-5. Figures 2 and 4 present the simulated core temperature responses when Soldiers perform continuous light work at two wind speeds. These figures show the response curves with a 10°F difference in WBGT index temperature between MOPP 4 and the other two configurations. Figures 3 and 5 present the simulated core temperature responses when Soldiers perform continuous moderate work at two wind speeds. These figures show the response curves with both 10°F and 20°F differences in WBGT index temperatures between MOPP 4 and the other two configurations.

Table 2. Equilibrium core temperatures calculated by the USARIEM-EXP simulation tool for Soldiers engaged in continuous light work (**250 W**) at two WBGT index temperatures (76°F and 86°F), both under compensable and uncompensable conditions. The equilibrium core temperatures were calculated for three uniforms configurations: (1) BDU, (2) MOPP 1, and (3) MOPP 4. All simulations were conducted at a wind speed of **2.2 mph**. Bold values indicate equivalent core temperature responses.

	76°F WBGT (86°F, 50% rh)	76°F WBGT (76°F, 100% rh)	86°F WBGT (109°F, 20% rh)	86°F WBGT (95°F, 58% rh)
Hot weather BDU	37.7°C	37.7°C	38.0°C	38.0°C
MOPP 1	37.8°C	37.8°C	38.1°C	38.1°C
MOPP 4	38.2°C	38.1°C	38.7°C	38.7°C

Table 3. Equilibrium core temperatures calculated by the USARIEM-EXP simulation tool for Soldiers engaged in continuous moderate work (**425 W**) at two WBGT index temperatures (66°F and 86°F), both under compensable and uncompensable conditions. The equilibrium core temperatures were calculated for three uniforms configurations: (1) BDU, (2) MOPP 1, and (3) MOPP 4. All simulations were conducted at a wind speed of **2.2 mph**. Bold values indicate equivalent core temperature responses.

	66°F WBGT (76°F, 44% rh)	66°F WBGT (66°F, 100% rh)	86°F WBGT (109°F, 20% rh)	86°F WBGT (95°F, 58% rh)
Hot weather BDU	38.2°C	38.2°C	39.0°C	39.0°C
MOPP 1	38.4°C	38.4°C	39.0°C	39.2°C
MOPP 4	39.0°C*	39.0°C*	40.6°C	40.6°C

*During continuous moderate work, it requires approximately a 20°F decrease in the WBGT index temperature for equilibrium core temperature in MOPP 4 to be the same as in BDU or MOPP 1.

Table 4. Equilibrium core temperatures calculated by the USARIEM-EXP simulation tool for Soldiers engaged in continuous light work (**250 W**) at two WBGT index temperatures (76°F and 86°F), both under compensable and uncompensable conditions. The equilibrium core temperatures were calculated for three uniforms configurations: (1) BDU, (2) MOPP 1, and (3) MOPP 4. All simulations were conducted at a wind speed of **4.5 mph**. Bold values indicate equivalent core temperature responses.

	76°F WBGT (86°F, 50% rh)	76°F WBGT (76°F, 100% rh)	86°F WBGT (109°F, 20% rh)	86°F WBGT (95°F, 58% rh)
Hot weather BDU	37.6°C	37.5°C	37.9°C	37.9°C
MOPP 1	37.7°C	37.7°C	37.9°C	37.9°C
MOPP 4	38.1°C	38.0°C	38.6°C	38.6°C

Table 5. Equilibrium core temperatures calculated by the USARIEM-EXP simulation tool for Soldiers engaged in continuous moderate work (**425 W**) at two WBGT index temperatures (66°F and 86°F), both under compensable and uncompensable conditions. The equilibrium core temperatures were calculated for three uniforms configurations: (1) BDU, (2) MOPP 1, and (3) MOPP 4. All simulations were conducted at a wind speed of **4.5 mph**. Bold values indicate equivalent core temperature responses.

	66°F WBGT (76°F, 44% rh)	66°F WBGT (66°F, 100% rh)	86°F WBGT (109°F, 20% rh)	86°F WBGT (95°F, 58% rh)
Hot weather BDU	38.2°C	38.1°C	38.8°C	38.8°C
MOPP 1	38.3°C	38.3°C	38.7°C	38.9°C
MOPP 4	38.9°C*	38.8°C*	40.4°C	40.4°C

*During continuous moderate work, it requires approximately a 20°F decrease in the WBGT temperature for equilibrium core temperature in MOPP 4 to be the same as in BDU or MOPP 1.

Figure 2. Core temperature responses calculated by the simulation tool USARIEM-EXP for Soldiers engaged in continuous light work (**250 W**) in three conditions: (1) clothing is BDU, wind is **2.2 mph**, and WBGT is 86°F; (2) clothing is MOPP 1, wind is **2.2 mph**, and WBGT is 86°F; and (3) clothing is MOPP 4, wind is **2.2 mph**, and WBGT is 76°F.

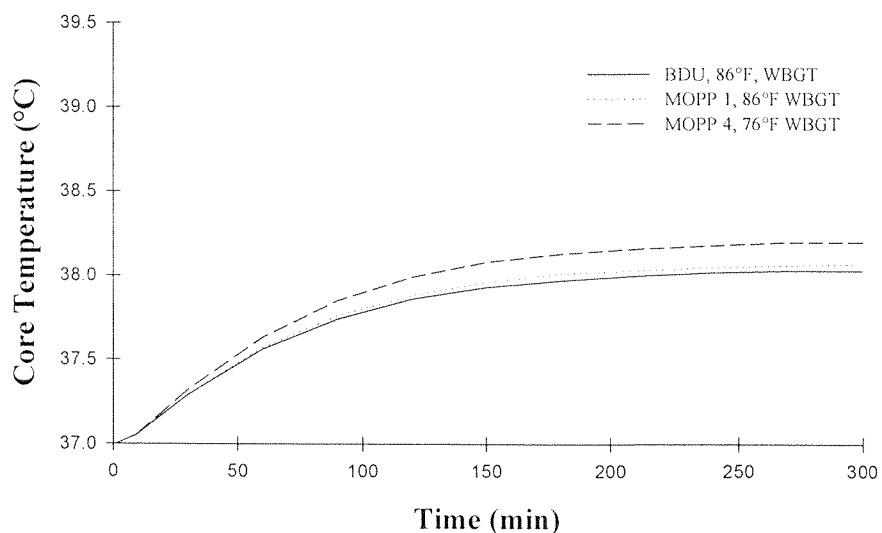


Figure 3. Core temperature responses calculated by the simulation tool USARIEM-EXP for Soldiers engaged in continuous moderate work (**425 W**) in four conditions: (1) clothing is BDU, wind is **2.2 mph**, and WBGT is 86°F; (2) clothing is MOPP 1, wind is **2.2 mph**, and WBGT is 86°F; (3) clothing is MOPP 4, wind is **2.2 mph**, and WBGT is 76°F; and (4) clothing is MOPP 4, wind is **2.2 mph**, and WBGT is 66°F.

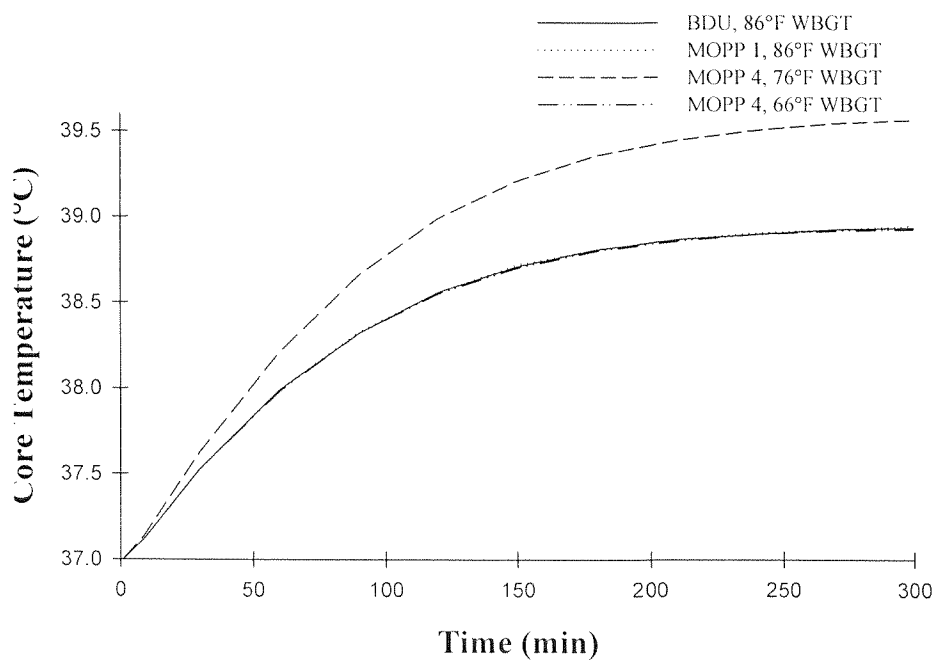


Figure 4. Core temperature responses calculated by the simulation tool USARIEM-EXP for Soldiers engaged in continuous light work (**250 W**) in three conditions: (1) clothing is BDU, wind is **4.5 mph**, and WBGT is 86°F; (2) clothing is MOPP 1, wind is **4.5 mph**, and WBGT is 86°F; and (3) clothing is MOPP 4, wind is **4.5 mph**, and WBGT is 76°F.

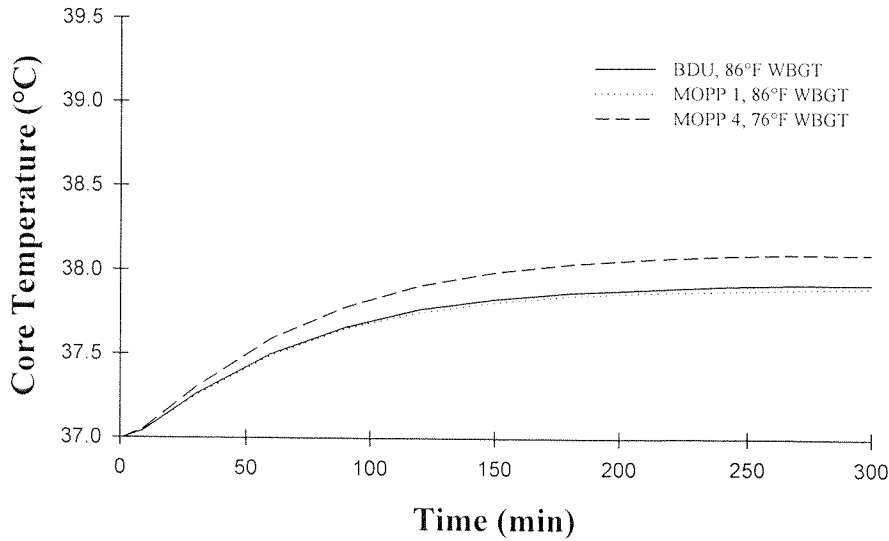
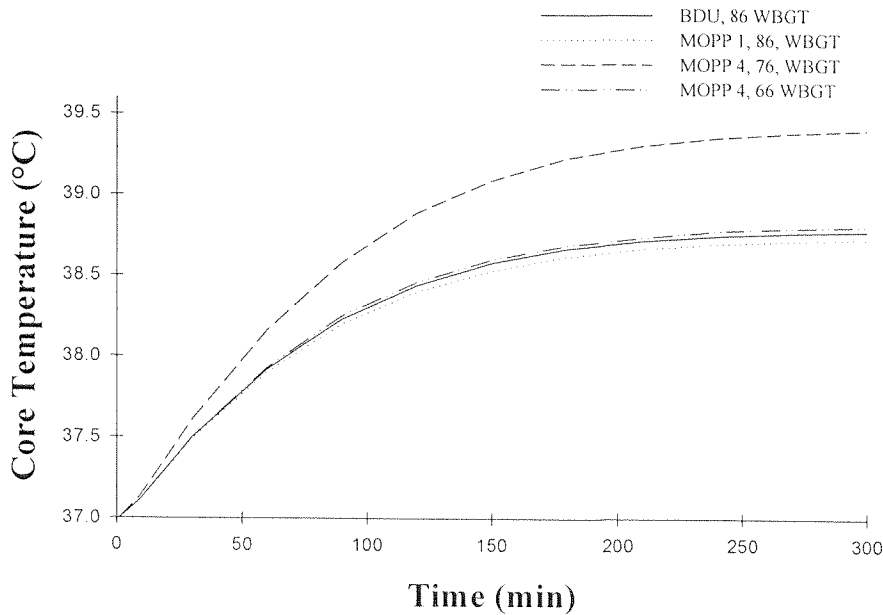


Figure 5. Core temperature responses calculated by the simulation tool USARIEM-EXP for Soldiers engaged in continuous moderate work (**425 W**) in four conditions: (1) clothing is BDU, wind is **4.5 mph**, and WBGT is 86°F; (2) clothing is MOPP 1, wind is **4.5 mph**, and WBGT is 86°F; (3) clothing is MOPP 4, wind is **4.5 mph**, and WBGT is 76°F; and (4) clothing is MOPP 4, wind is **4.5 mph**, and WBGT is 66°F.



BODY ARMOR

Table 6 shows both the measured core temperature responses in men wearing body armor after working 100 minutes, and the simulated core temperatures of men wearing only the BDU after working 100 minutes in the same compensable environment conditions. Simulated values were used for the BDU-only conditions, as these configurations were not tested in the body armor experiments.

Table 6. Final core temperatures for Soldiers engaged in 100 minutes of continuous moderate work (**425 W**) in a compensable WBGT index environment (82°F with low humidity) at two wind speeds (**2.2 and 5.6 mph**). Temperatures for the BDU+armor configurations are mean values of experimental human subject data. Temperatures for the BDU only are calculated by the USARIEM-EXP simulation tool.

	82°F WBGT (104°F, 20% rh) Wind 2.2 mph	82°F WBGT (104°F, 20% rh) Wind 5.6 mph
BDU+ armor Measured	38.3°C	38.1°C
BDU Simulated	38.3°C	38.2°C

The simulations for the impact of wearing body armor in a closed configuration over the BDU in uncompensable heat strain environments were calculated at 95°F (35°C), 75% rh, WBGT 90°F (32.2°C). The simulations were run to calculate core temperature at 100 minutes, with wind speeds of both 2.2 and 5.6 mph, and work rates of both 250 and 425 W. To validate the current WBGT index temperature offset of 5°F (2.8°C) for the impact of body armor, the USARIEM-EXP was used to simulate the equilibrium core temperature at 100 minutes for men wearing only the BDU using the same work rates and wind speeds, at both WBGT 90°F and 95°F. The simulated core temperature responses at both WBGT index temperatures are shown in Table 7 for the 250 W metabolic rate, and in Table 8 for the 425 W metabolic rate. The simulations show that lowering the WBGT index temperature by 5°F when wearing body armor results in similar core temperature responses to wearing only the BDU in these uncompensable environments.

Table 7. Final core temperatures calculated by the USARIEM-EXP simulation tool for Soldiers engaged in 100 minutes of continuous light work (**250 W**) in two uncompensable WBGT index environments (90°F and 95°F with high humidity) at two wind speeds (**2.2 and 5.6 mph**). The final core temperatures were calculated for two uniform configurations: (1) BDU and (2) BDU+armor. Bold values indicate equivalent core temperature responses.

	90°F WBGT (95°F, 75% rh) Wind 2.2 mph 250 W	95°F WBGT (100°F, 75% rh) Wind 2.2 mph 250 W	90°F WBGT (95°F, 75% rh) Wind 5.6 mph 250 W	95°F WBGT (100°F, 75% rh) Wind 5.6 mph 250 W
BDU	38.0°C	38.4°C	37.8	38.3°C
BDU+Armor	38.4°C	38.7°C	38.2°C	38.6°C

Table 8. Final core temperatures calculated by the USARIEM-EXP simulation tool for Soldiers engaged in 100 minutes of continuous moderate work (**425 W**) in two uncompensable WBGT index environments 90°F and 95°F with high humidity) at two wind speeds (**2.2 and 5.6 mph**). The final core temperatures were calculated for two uniform configurations: (1) BDU and (2) BDU+armor. Bold values indicate equivalent core temperature responses.

	90°F WBGT (95°F, 75% rh) Wind 2.2 mph 425 W	95°F WBGT (100°F, 75% rh) Wind 2.2 mph 425 W	90°F WBGT (95°F, 75% rh) Wind 5.6 mph 425 W	95°F WBGT (100°F, 75% rh) Wind 5.6 mph 425 W
BDU	39.0°C	39.5°C	38.7°C	39.3°C
BDU+Armor	39.6°C	39.9°C	39.4°C	39.8°C

DISCUSSION

NBC PROTECTIVE CLOTHING

The simulations using the USARIEM-EXP heat strain decision aid indicated that there was little difference in the level of heat strain imposed on the soldier when he wore either the BDU or chemical protective clothing in the open (MOPP 1) configuration when performing light or moderate levels of work. However, when chemical protective clothing was worn closed in the MOPP 4, the simulation indicated a significant level of increased heat strain relative to wearing only the BDU. When performing continuous light work (250 W), it required a reduction in the WBGT index temperature of approximately 10°F (5.6°C) for the simulated equilibrium core temperature reached in MOPP 4 to be the same as in MOPP 1 or in the BDU. When performing continuous moderate work (425 W), it required a reduction in the WBGT index temperature of approximately 20°F (11.2°C) for the simulated equilibrium core temperature reached in MOPP 4 to be the same as in MOPP 1 or in the BDU. Therefore, when using the heat category tables provided for the field (Table 1), it is clear that having to perform light work in the MOPP 4 configuration would increase the heat category by three levels. At

moderate work, any WBGT index temperature above 70°F would place a Soldier in Heat Category 5 when wearing MOPP 4.

BODY ARMOR

We compared the USARIEM-EXP simulation against human physiological data and found that there were no differences in equilibrium core temperature whether or not armor was worn over the hot weather BDU in a compensable heat stress environment. However, when the simulation was run for both light and moderate work rates in an uncompensable environment, there was an increased level of heat strain if body armor was worn. These simulations indicate that when evaporative cooling is limited, armor increased the core temperature response equivalent to wearing only the BDU in an environment that was 5°F hotter on the WBGT temperature index. This finding validates the current guidance for a 5°F increase in the WBGT index temperature when body armor is worn.

CONCLUSIONS

The findings of these analyses indicate that WBGT index temperatures should be corrected by the following offsets: (1) +10°F at light work when wearing MOPP 4, (2) +20°F at moderate work when wearing MOPP 4, (3) no adjustment if skin is dry when wearing body armor with the BDU, and (4) +5°F if skin is wet when wearing body armor with the BDU.

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