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THERMAL MANIKIN EVALUATION AND PREDICTED THERMAL RESPONSES FOR THE HOMELAND RESPONSE FORCE HAZMAT SUITS

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14. ABSTRACT
This report provides a quantitative assessment of the biophysical properties of the Homeland Response Force HAZMAT protective ensembles; the Blauer XRT and Lion MT-94 suits along with the Chemical Biological Radiological and Nuclear (CBRN) CAP1 Powered Air-Purifier Respirator (PAPR) face mask and waist worn blower. Measured and modeled comparisons were made of the thermal properties and predicted human thermal responses for each ensemble while working at three intensities and in six environmental conditions (three hot/warm and three freezing/cold). Methods: Standard tests to measure thermal and evaporative resistances (Rt and Ret) were conducted for three ensembles. Predictions of human responses were made for three work intensities (150W, 250W, and 425W) in six environmental conditions (-10°C, 60% RH; 0°C, 60% RH; 5°C, 60% RH; 20°C, 50% RH; 35°C, 75% RH; 50°C, 20% RH). Results: Biophysical assessments found lower thermal resistance and evaporative potential (im/clo) for the Blauer XRT uniform.

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EXECUTIVE SUMMARY

Introduction: This report provides a quantitative assessment of the biophysical properties of the Homeland Response Force HAZMAT protective ensembles ; the Blauer XRT and Lion MT-94 suits along with the Chemical Biological Radiological and Nuclear (CBRN) CAP1 Powered Air-Purifier Respirator (PAPR) face mask and waist worn blower. Measured and modeled comparisons were made of the thermal properties and predicted human thermal responses for each ensemble while working at three intensities and in six environmental conditions (three hot/warm and three freezing/cold). **Methods:** Standard tests to measure thermal and evaporative resistances (R_t and R_{et}) were conducted (ASTM F1291-16 & ASTM F2370-16) for three ensembles. Predictions of human responses were made for three work intensities (150W, 250W, and 425W) in six environmental conditions (-10°C, 60% RH; 0°C, 60% RH; 5°C, 60% RH; 20°C, 50% RH; 35°C, 75% RH; 50°C, 20% RH). **Results:** Biophysical assessments found lower thermal resistance and evaporative potential (i_m/clo) for the Blauer XRT uniform. Additionally the Air Force summer under layer had a lower thermal resistance and evaporative potential (i_m/clo) than the Army underlayer. The Army under layer had a lower thermal resistance and evaporative potential (i_m/clo) than the Air Force under layer. Collectively this causes the Air Force uniforms to allow users to be cooler in summer and warmer in winter. Accordingly predicted maximal work times were slightly higher for the Blauer XRT Air Force at summer work intensities and environmental conditions; while the Lion MT-94 Army were higher in winter conditions.

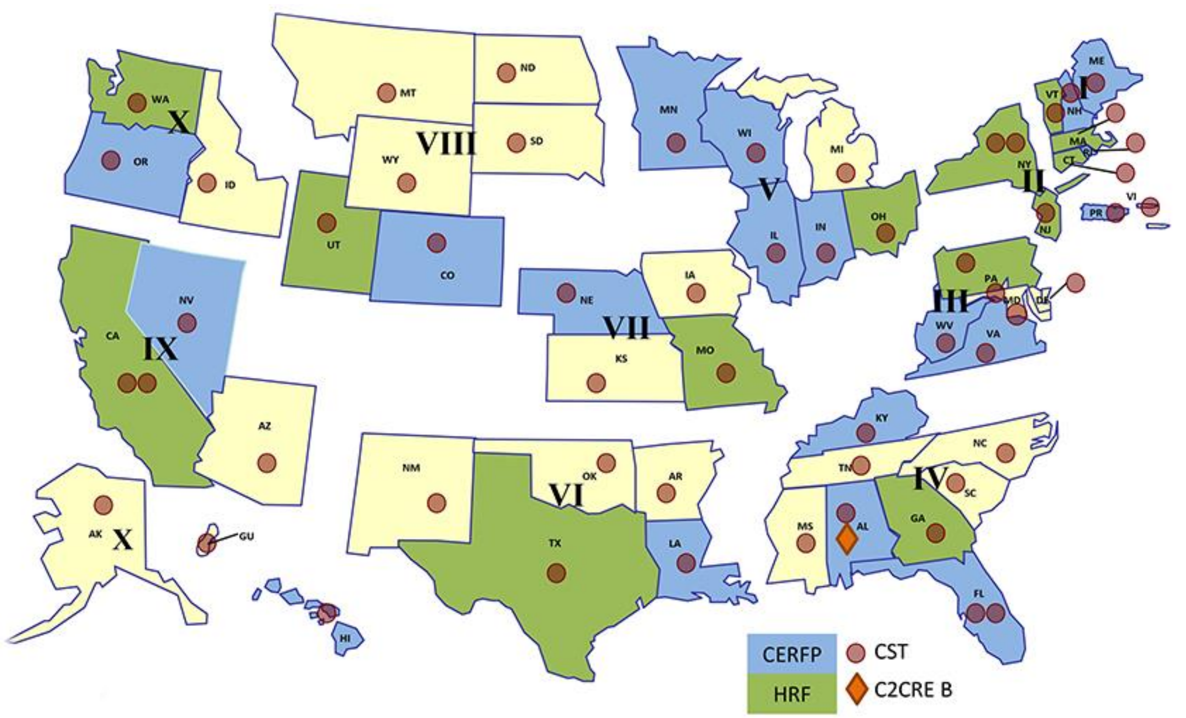
INTRODUCTION

Background

The National Guard Bureau (NGB) seeks to extend down-range operations of their Homeland Response Force (HRF) and Chemical, Biological, Radiological, Nuclear and Explosive (CBRNE) Enhanced Response Force Package (CERF-P) personnel. The HRF and CERF-P are part of the domestic response force for catastrophic events (State Response: Title: 32). For the HRF there are 10 units and for the CERF- P there are 17 units. There are 57 Weapons of Mass Destruction-Civil Support Teams (WMD-CSTs).

Each state as well as Puerto Rico, the U.S. Virgin Islands and Guam have their own WMD-CSTs; while Florida, California, and New York possess two teams. The WMD-CSTs, HRFs, and CERF-Ps, provide an integrated response to a potential domestic CBRN incident. Figure 1 depicts the locations of each NGB asset by region. There are 10 HRF areas of responsibility locations (states that are connected together on the map) with 17 CERF-P assets (some groups of HRF sets of states have multiple CERF-P groups).

Figure 1. Organization and location of National Guard Bureau Weapons of Mass Destruction Civil Support Team (WMD-CST), Homeland Response Force (HRF) and Chemical, Biological, Radiological, Nuclear and Explosive (CBRNE) Enhanced Response Force Package (CERF-P) Units (From https://mil.wa.gov/homeland-response-force; Accessed 19 August 2021).



In total there are approximately 5,830 HRF and 3451 CERF-P National Guard Soldiers and Airmen. During any particular training exercise or mission, up to 150 personnel from both HRF and CERF-P units could be encapsulated in CBRN personal protective equipment (PPE) while taking on functions of Search and Extraction (S&E) , Decontamination (DECON) and Fatality Search Recovery Team (FSRT). The WMD-CSTs are expected to respond to a CBRN incident within one to three hours and their main mission is to detect, identify, and communicate the threat. The CERF-P units are expected to be on-site within three to six hours, and their mission involves searching for live and dead victims, stabilizing live victims and extracting and preparing of fatalities. The HRF units are larger units and they serve the same down-range functions as the CERF-Ps but provide higher and more Command and Control capabilities. While each mission is different, WMD-CST missions tend to be shorter in duration, (e.g., a few hours); while HRF and CERF-P missions can be more protracted (e.g., hours to multiple days) (1).

The HRF and CERF-P missions often involve heavy work, i.e., moving and/or carrying heavy bodies to a decontamination area while encapsulated in CBRN personal protective equipment (PPE). Thermal strain affects both health and performance of the individuals. Heat injuries and heat illnesses are real possibilities (2) as are compromised cognitive (3) and physical performance (4). The NGB has recognized these limitations and has made the acquisition of mission planning tools one their top priorities (5). USARIEM possesses mission planning tools for both hot and cold environments. For example two apps for hot weather operations that the NGB are interested in (5) are the Heat Strain Decision Aid (HSDA) (6), the Soldier Water Estimation Tool (SWET) (7). For cold weather operations the NGB seeks (5) the Cold Weather Ensemble Decision Aid (CoWEDA) (8). While these tools have been proven valid and reliable; the accuracy of the estimates depends on quality inputs for clothing and PPE worn as well as the particular activities the Soldier or Airmen are engaged in. To date the specific PPE worn by the HRF and CERF-P Soldiers and Airmen have not been incorporated into CoWEDA, HSDA or their associated models. Therefore, the purpose of the test described within this report was to obtain the necessary biophysical properties of the HRF and CERF-P personnel's PPE. More specifically, this work was conducted to determine the total thermal resistance and evaporative resistances at multiple wind speeds for the Blauer XRT and Lion MT-94 Homeland Response Force hazardous material (HAZMAT) PPE suits over the summer and winter Army and Air Force physical training (PT) uniforms.

The goal of this study was to provide a quantitative comparison of the thermal properties of these ensembles as well as predicted human thermal responses for each of them at three work intensities and at three summer and three winter environmental conditions.

METHODS

Testing was conducted using a 20 zone articulated thermal manikin (Thermetrics, Seattle, WA, http://www.thermetrics.com/, 'Newton' model) located in the USARIEM environmental chamber, room 232C. Testing was performed according to ASTM standard F1291-16 for thermal resistance (R_t) and F2370-16 for evaporative resistance (R_{et}) (9-10). The environmental conditions were an air temperature (T_a) 20°C and 50% relative humidity (RH) for the thermal resistance tests and T_a 35°C and 40% RH for the evaporative resistance tests. In addition to performing the testing at a wind velocity (*V*) of 0.4 $m \cdot s^{-1}$ as prescribed in the test methods, R_t and R_{et} were also measured at two additional wind velocities (approximately 1.2 $m \cdot s^{-1}$ and 2.0 $m \cdot s^{-1}$).

After the R_t and R_{et} measurements were collected, R_t was converted from SI units ($m^2 \cdot K \cdot W^{-1}$) to clo units, where 1 clo = 0.155 $m^2 \cdot K \cdot W^{-1}$. The evaporative potential (i_m/clo) was also calculated from the R_t and R_{et} measurements and was used as a measure of the ensembles maximum evaporative potential (11, 12). R_t and R_{et} were converted into these different forms for modeling input to the Heat Strain Decision Aid and for comparison with historical data. Collecting R_t and R_{et} data at three wind velocities is necessary to produce a power regression equation, which is also necessary for input to some models and the equation also describes the change in R_t and R_{et} at air velocities between 0.4 $m \cdot s^{-1}$ and 2.0 $m \cdot s^{-1}$ and potentially allows to extrapolate to air velocities outside this range (13, 14).

Garment Identification

Two Chemical Biological Radiological and Nuclear (CBRN) uniforms were tested; the Bauer XRT (Blauer Manufacturing Co., Inc., Boston, MA, https://www.blauer.com/), and the Lion MT-94 (LION Group, Inc., Dayton, OH, https://www.lionprotects.com). Both uniforms included white cotton glove liners, cotton ankle socks, CBRN CAP1 Powered Air-purifier Respirator (PAPR) face mask and waist worn blower (Airboss Defense Group, Landover, MD, https://www.adg.com/) with a Camelbak hydration backpack (Camelbak, Petaluma, CA, https://www.camelbak.com/military/).

a. **Blauer Air Force Summer** – Blauer XRT CB suit over the Air Force blue PT running shorts and gray short sleeve t-shirt, OnGuard Hazmax, green hazmat steel toe boots (Dunlop Protective Footwear, Havre De Grace, MD), https://www.dunlopboots.com/us).
b. **Blauer Army Summer** – Blauer XRT CB suit over the Army black PT running shorts and black short sleeve t-shirt, OnGuard Hazmax, green hazmat steel toe boots.
c. **Blauer Air Force Winter** – Blauer XRT CB suit over the Air Force blue PT long pants, gray short sleeve t-shirt and blue PT jacket, OnGuard Hazmax, green hazmat steel toe boots.

d. **Blauer Army Winter** – Blauer XRT CB suit over the Army black PT long pants, black short sleeve t-shirt and PT jacket, OnGuard Hazmax, green hazmat steel toe boots.
e. **Lion Air Force Summer** – Lion MT-94 CB training suit over the Air Force pt blue running shorts and gray short sleeve t-shirt, Tingley HazProof, orange hazmat steel toe boots (Tingley Rubber Corp., Piscataway, NJ, https://www.tingleyrubber.com/).
f. **Lion Army Summer** – Lion MT-94 CB training suit over the Army black PT running shorts and black short sleeve t-shirt, Tingley HazProof, orange hazmat steel toe boots.
g. **Lion Air Force Winter** – Lion MT-94 CB training suit over the Air Force blue PT long pants, gray short sleeve t-shirt and blue PT jacket, Tingley HazProof, orange hazmat steel toe boots.
h. **Lion Army Winter** – Lion MT-94 CB training suit over the Army black PT long pants, black short sleeve t-shirt and PT jacket, Tingley HazProof, orange hazmat steel toe boots.

Figure 2. Thermal manikin wearing the Air Force summer and winter physical fitness uniforms

Figure 3. Thermal manikin wearing the Army summer and winter physical fitness uniforms.

Figure 4. Thermal manikin wearing the Blauer XRT HAZMAT suit.

Figure 5. Thermal manikin wearing the Lion MT-94 HAZMAT suit.

RESULTS

Total thermal resistance in clo units and evaporative potential (i_m/clo) for each configuration measured at 1.0 m•s^{-1} wind speed are shown in Tables 1 and 2, as well as in Figures 5 and 6.

Quantifying the impact of wearing a HAZMAT uniform on maximum work times is of significant interest to the military and public sectors (15-17). This is of particular interest for the HRF and CERF-P which not only trains regularly in these suits but also responds to emergency situations in all environments.

Table 1. Total thermal resistance at 1.0 m•s^{-1} wind speed for the eight ensembles tested.

		R_t (clo)	
		Blauer XRT	Lion MT-94
Summer	Army	1.38	1.65
	Air Force	1.29	1.57
Winter	Army	1.59	1.86
	Air Force	1.63	1.99

Note: lower values = less thermal resistance.

Table 2. Total evaporative potential (i_m/clo) at 1.0 m•s^{-1} wind speed for the eight ensembles tested.

		i_m/clo (dimensionless)	
		Blauer XRT	Lion MT-94
Summer	Army	0.096	0.014
	Air Force	0.143	0.010
Winter	Army	0.094	0.015
	Air Force	0.118	0.030

Note: higher i_m/clo = increased evaporative potential.

Figure 6. Total thermal resistance for the eight ensemble configurations tested

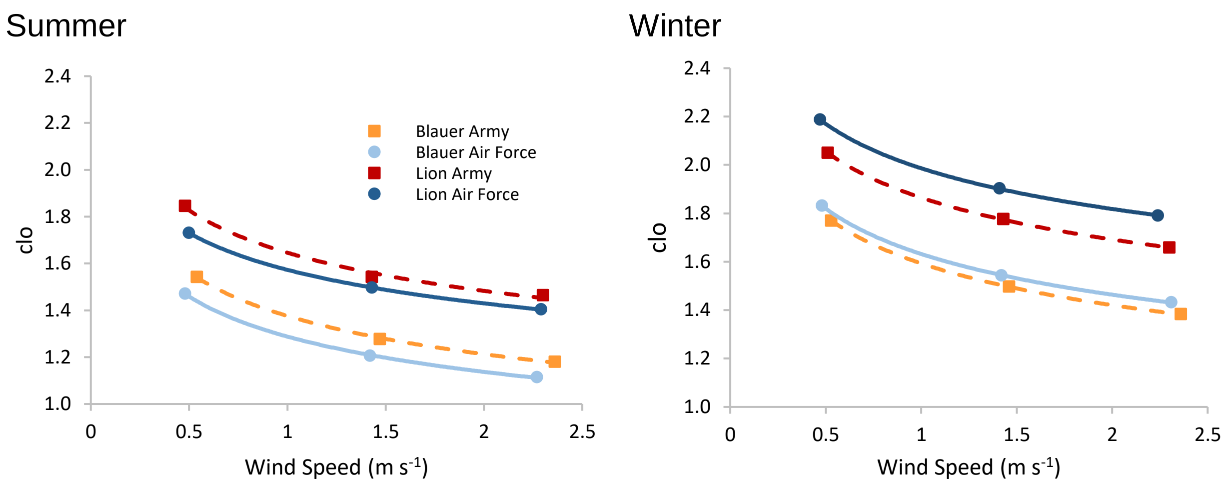
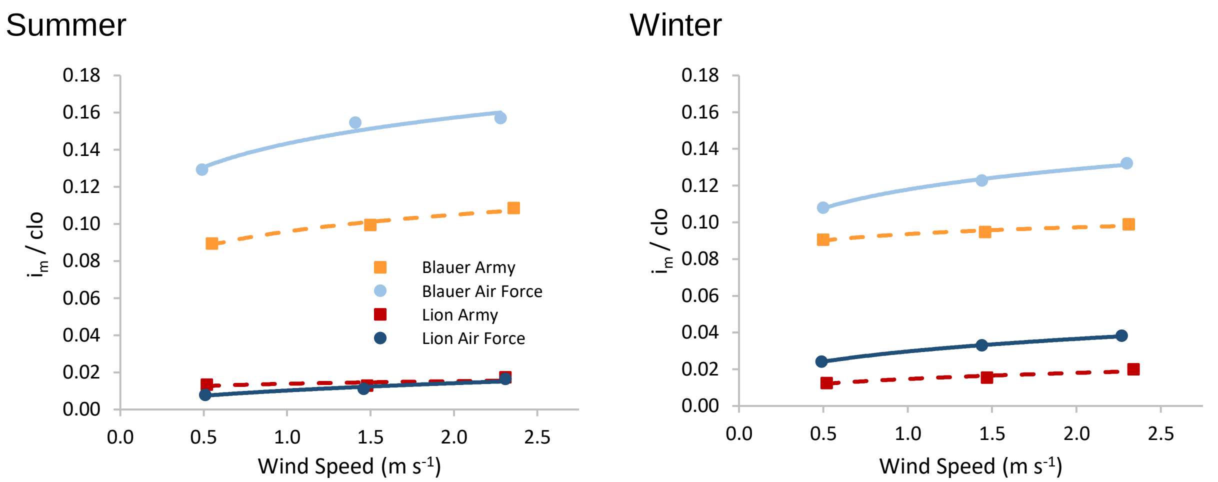


Figure 7. Evaporative potential (i_m/clo) for the eight ensemble configurations tested



Prediction modeling

USARIEM six cylinder thermoregulatory model (SCTM) (18, 19) was used to predict the maximum work time possible while wearing all uniforms before the core temperature exceeded 39.5°C. Three hot/warm environmental conditions were used: 50°C / 20% RH, 35°C / 75% RH, and 35°C / 50% RH. The SCTM is a rational model, and is based on first principles of physiology and the physical laws of heat transfer. The human body is subdivided into six segments representing the head, trunk, arms, legs, hands, and feet. It simulates the thermoregulatory actions: shivering heat production, vasodilation/vasoconstriction and sweat production. The model is validated from exposures to heat and cold (45°C to -40°C) and cold water immersion. Additionally, SCTM inputs include individual characteristics, intensity of activity, environmental conditions and clothing properties (i.e., thermal resistance and evaporative resistance) for each of the six body regions. Predicted outputs from SCTM include core temperatures, skin temperatures and sweat rates for six body regions. For each of these environments the model was run at three working metabolic rates: Very Light (150 W), Light (250 W), and Moderate (425 W). (Table 3)

The modeling principles from SCTM were converted to a user-friendly decision aid, Cold Weather Ensemble Decision Aid (CoWEDA) (8, 20-21). The CoWEDA guides end users to select and evaluate the most appropriate cold weather clothing relative to the anticipated activities and environmental conditions. The CoWEDA model was also used to predict the body endurance times while wearing the winter undergarments in cold environments before the core temperature dropped below 36°C where the risk of hypothermia is increased. Additionally the model was used to predict the endurance time of the hands and feet to drop to 5°C, the threshold where the probability of frostbite increases significantly. Three freezing/cold environmental conditions were used: -10ºC / 60% RH, 0ºC / 60% RH, and 5ºC / 60% RH. For each of these environments the model was also ran at three working metabolic rates: Very Light (150 W), Light (250 W), and Moderate (425 W).

All modeling assumed the conditions of full sun and 1.0 $m \bullet s^{-1}$ wind speed, with the wearer at normal hydration, 12 days of heat acclimation, and utilizing a standard man (176 cm height, 76 kg weight, and 1.8 m^2 surface area). The model was used to predict the core temperature and hand and foot skin temperatures while working at three intensities and eight distinct environments. Maximum work times in the heat is the time when the core temperature reaches 39.5°(15), for the cold is when core temperature drops to 36°C (20-21).

Summer posture

The SCTM was used to make predictions during a ‘Summer’ posture in three cool-hot environments. For each of these environments the model was run at three working metabolic rates: Very Light (150 W), Light (250 W), and Moderate (425 W). (Figures 7-9; Table 3)

Figure 8. Core temperature while wearing the eight ensembles at 20°C, 50% RH at three work intensities; Very Light (150W), Light (250W), and Moderate (425W).

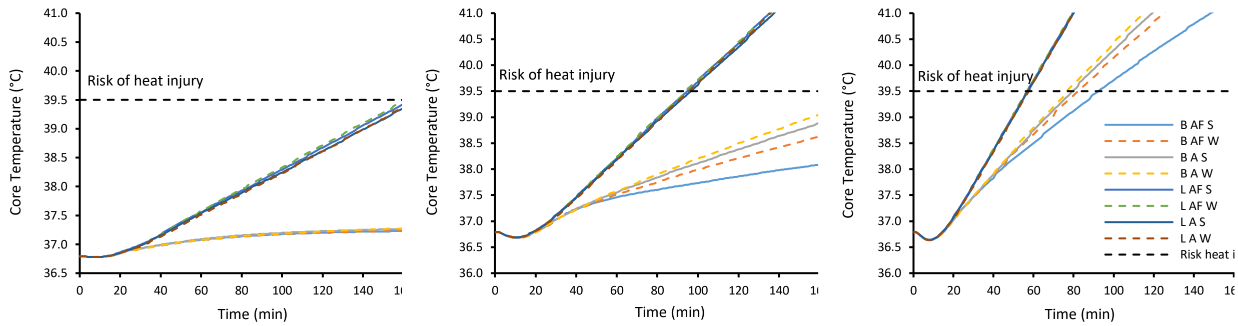


Figure 9. Core temperature while wearing the eight ensembles at 35°C, 75% RH at three work intensities; Very Light (150W), Light (250W), and Moderate (425W).

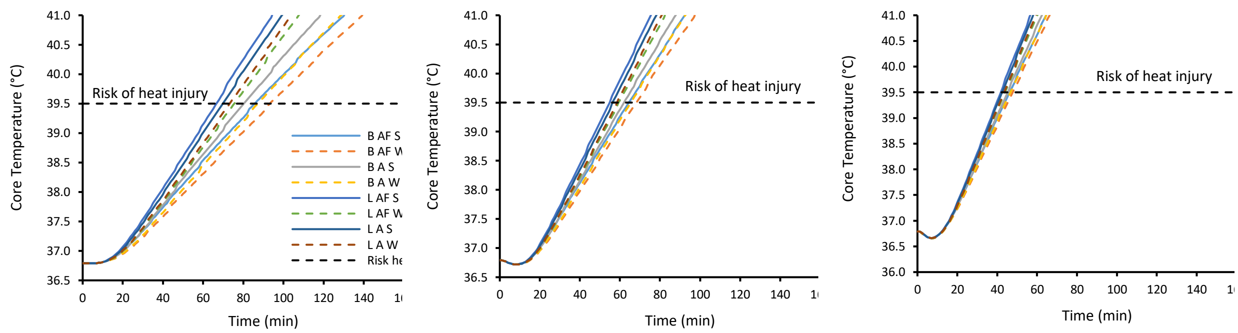


Figure 10. Core temperature while wearing the eight ensembles at 50°C, 20% RH at three work intensities; Very Light (150W), Light (250W), and Moderate (425W).

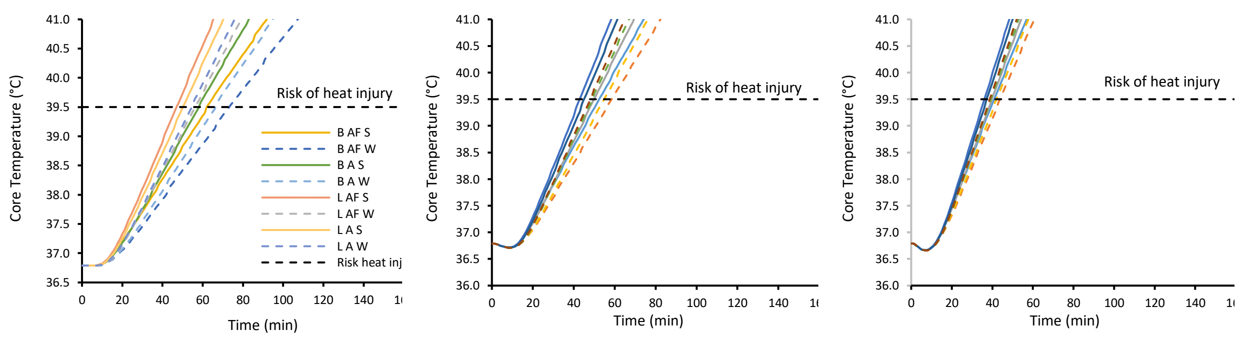


Table 3. Predicted results for maximum work duration in minutes while wearing the summer ensembles. Maximum work time before predicted body core temperature reaches 39.5°C indicating there's an increased risk of heat injury.

	T_a (°C)	RH%	Work (watts)	Max Work (min)
Blauer Air Force	50	20	150	66
			250	52
			425	40
	35	75	150	85
			250	64
			425	46
	20	50	150	300
			250	300
			425	92
Blauer Army	50	20	150	62
			250	49
			425	39
	35	75	150	80
			250	62
			425	45
	20	50	150	300
			250	213
			425	79
Lion Air Force	50	20	150	47
			250	42
			425	36
	35	75	150	66
			250	54
			425	41
	20	50	150	163
			250	94
			425	56
Lion Army	50	20	150	50
			250	45
			425	37
	35	75	150	69
			250	56
			425	42
	20	50	150	167
			250	96
			425	57

Winter posture

Body endurance time is the time until the predicted core temperature drops to 36°C, indicating there is an increased risk of hypothermia if the core temperature continues to decrease. The CoWEDA results for body endurance time predicted body core temperatures to drop below 36°C while wearing the four winter uniforms. The model was run for a maximum time of 300 minutes.

Endurance time for hands and feet is the time until the predicted skin temperature drops below 5°C indicating that a cold injury is likely to occur soon. Below this threshold, the probability of cold injury increases significantly. Additional symptoms, loss of manual dexterity, pain and significant loss of manual performance, and intolerable pain, begin to occur as hands and feet skin temperature reach 20°C, 15°C, and 10°C respectively (22).

Figure 11. Hand and foot skin temperature while wearing the eight ensembles at -10°C / 60% RH environment, working at three intensities; Very Light (150W), Light (250W), and Moderate (425W).

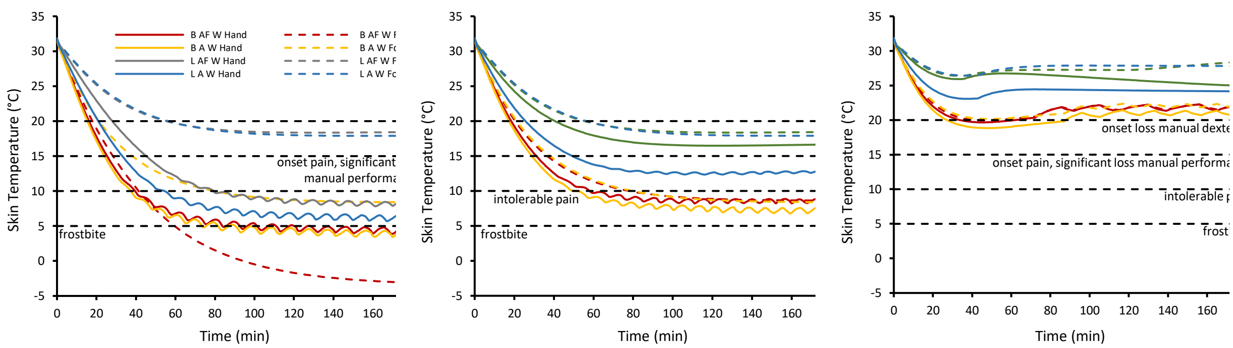


Figure 12. Hand and foot skin temperature while wearing the eight ensembles at 0°C 60% / RH environment working at three intensities; Very Light (150W), Light (250W), and Moderate (425W).

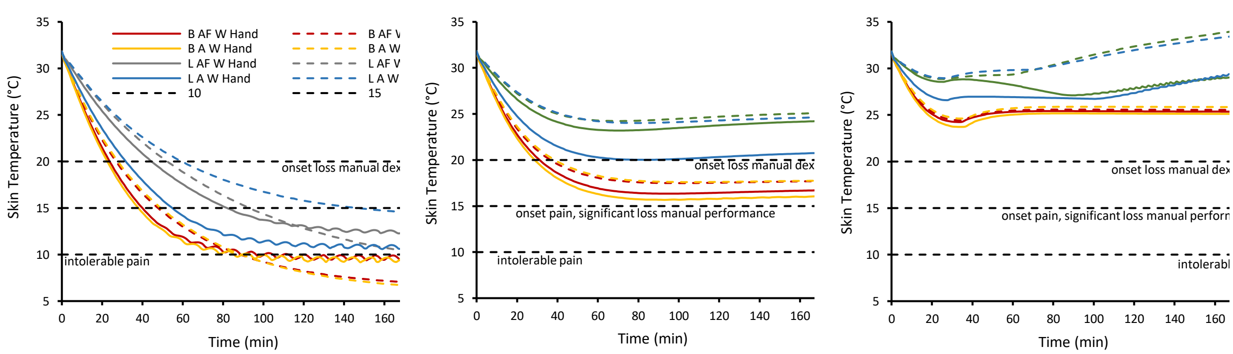
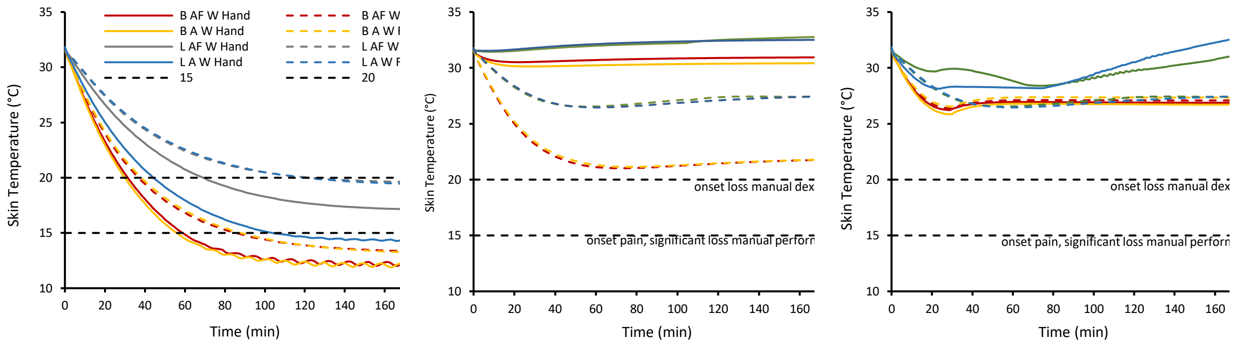


Figure 13. Hand and foot skin temperature while wearing the eight ensembles at 5°C / 60% RH working at three intensities; Very Light (150W), Light (250W), and Moderate (425W).



DISCUSSION

Balancing CBRN protection with the risk of thermal burden is a continuous challenge during HAZMAT events due to CBRN outbreaks (16-17, 23-26). Protective ensembles decrease the ability for CBRN threats to affect humans by limiting their entrance into the suit and exposure to the body to these toxic agents. However, these CBRN PPE ensembles by their designed impermeable nature, while protecting from external threat also impede heat dissipation by limiting cutaneous evaporative heat loss. This balance can become important to consider as it increases the risk of heat stress for individual wearers. The use of apps to better mission plan is one strategy to extend downrange operations safely.

There are countermeasures that can be used to mitigate the risk of heat strain, to include effectively observing maximum work time. Managing the amount of work and rest will have significant benefit to the individual by allowing them time to cool off during active periods or providing active or passive cooling via specialized equipment (27-32).

Biophysical assessment of these uniforms showed the lighter Blauer XRT, which weighs 3.4 pounds, having a slight advantage in predicted maximum work times due to its lower thermal resistance and evaporative resistance when compared to the heavier Lion MT-94, which weighs 5.5 pounds, and is highly impermeable.

Although the lower resistance and lower evaporative resistance proved to be an advantage for the Blauer XRT in the Summer posture both uniforms still exceeded the 39.5°C before the end of 300 minute modeling scenario (Table 3). Heat injury threshold was reached in all modeled cool-hot conditions with the exception of two instances at the 20°C / very light work and one instance at 20°C / light work while wearing the Blauer XRT summer posture uniform.

In the freezing/cold predicted modeling, the Lion MT-94 showed longer maximum work times due to its higher insulation value. Only one modeling scenario the Lion MT-94 dropped below the 5°C frostbite threshold, it lasted twice as long as the Blauer XRT. Predicted hand frostbite threshold of 5°C was reached only in the -10°C / very light work after 92 minutes for the Blauer XRT Air Force and 81 minutes for the Blauer XRT Army winter ensembles. Predicted endurance time for the foot was also reached for both uniforms in the -10°C / very light work environment after 59 minutes for the Blauer XRT Air Force, 61 minutes for the Blauer XRT Army, 130 minutes for the Lion MT-94 Air Force, and 130 minutes for the Lion MT-94 Army.

CONCLUSION

Data and analyses from this report provide quantitative information regarding the specific uniforms and use cases for these HRF and CERF-P ensembles. Biophysical data from this report also allow for more tailored modeling and simulation regarding specific working conditions (e.g., various activity rates, durations, and environmental conditions). More importantly, data from this report enable the incorporation of these clothing ensembles into existing decision aids (HSDA and CoWEDA) in order to be prepared specifically for and transitioned to the NGB.

References

1. National Guard Bureau. *Chief National Guard Bureau Manual.* National Guard Bureau (CNGBM 3510.01) Washington, D.C., 25 August 2016.

2. Tharion WJ., Potter AW, Duhamel CM, Karis AJ, Buller MJ, and Hoyt RW. Real-time physiological monitoring while encapsulated in personal protective equipment. *Journal of Sport and Human Performance, 1(4)*, 14-21, 2013.

3. Schmit C, Hausswirth C, Le Meur Y, and Duffield R. Cognitive functioning and heat strain: performance responses and protective strategies. *Sports Medicine*, *47*, 1289-1302, 2017.

4. Hargreaves M. Physiological limits to exercise performance in the heat. *Journal of Science and Medicine in Sport*, 11, 66-71, 2008.

5. Reyes H. Chemical, Biological, Radiological, Nuclear, Explosive (CBRNE) Rapid Acquisition Division (C-RAD) Commercial Off-the-Shelf (COTS) Modernization Process for National Guard Bureau (NGB) Homeland Response Force (HRF) and CBRNE Enhanced Response Force Package (CERFP). Memorandum for Joint Product Manager Chemical, Biological, Radiological, Nuclear, Explosive Analytics and Response Systems, ATTN: SFAE-CBD-GN-C (LTC Alan Stevens), NGB-J39, Aberdeen, MD, 16 November 2020.

6. Potter AW, Blanchard LA, Friedl, KE, Cadarette BS, and Hoyt RW. Mathematical prediction of core body temperature from environment, activity, and clothing: The heat strain decision aid (HSDA). *Journal of Thermal Biology*, *64, 78-85*, 2017.

7. Charkoudian N, Kenfick RW, Lapadula AJ, Swiston AJ, Patel T, Blanchard LA, et al. Planning military drinking water needs: development of a user-friendly smart device application. *Military Medicine*, *181(9)*, 1142-1148, 2016.

8. Potter, AW, Looney DP, Santee WR, Gonzalez JA, Welles AJ, Srinivasan S, et al. Validation of new method for predicting human skin temperature during cold exposure: The Cold Weather Ensemble Decision Aid (CoWEDA). *Informatics in Medicine Unlocked*, *18*, 100301, 2020.

9. ASTM. Standard Test Method for Measuring the Thermal Insulation of Clothing Using a Heated Manikin [ASTM, F1291–16]. ASTM Philadelphia, Pa.; 2016.

10. ASTM. Standard Test Method for Measuring the Evaporative Resistance of Clothing Using a Sweating Manikin [ASTM F2370–16]. American Society of Testing Materials International: ASTM Philadelphia, Pa.; 2016.

11. Woodcock AH. Moisture permeability index - a new index for describing evaportative heat transfere through fabric systems. Technical Report No. EP-149, 1961.

12. Gonzalez RR. Biophysics of heat transfer and clothing considerations. In: Pandolf KB, Sawka MN, Gonzalez RR, editors. Human Performance Physiology and Environmental Medicine at Terrestrial Extremes. Indianapolis, IN: Benchmark Press, Inc.; 1988. p. 45-95.

13. Potter AW, Gonzalez JA, Karis AJ, Rioux TP, Blanchard LA, Xu X. Impact of estimating thermal manikin derived wind velocity coefficients on physiological modeling. US Army Research Institute of Environmental Medicine, Natick, MA, 01760, USA, Technical Report, T14-7, 2014.

14. Potter AW. Method for estimating evaporative potential (im/clo) from ASTM standard single wind velocity measures. US Army Research Institute of Environmental Medicine, Natick, MA, 01760, USA, Technical Report, T16-14, 2016.

15. Potter AW, Blanchard LA, Friedl KE, Cadarette BS, Hoyt RW. Mathematical prediction of core body temperature from environment, activity, and clothing: The heat strain decision aid (HSDA). *Journal of Thermal Biology,* 64:78-85, 2017.

16. Cadarette BS, Levine L, Staab JE, Kolka MA, Correa M, Whipple M, et al. Heat strain imposed by toxic agent protective systems. *Aviation, Space and Environmental Medicine,* 72(1):32-7, 2001.

17. Potter AW, Gonzalez JA, Xu X. Ebola response: modeling the risk of heat stress from personal protective clothing. *PloS One*, 10(11):e0143461, 2015.

18. Xu X, Tikuisis P, Gonzalez R, Giesbrecht G. Thermoregulatory model for prediction of long-term cold exposure. *Computers in Biology and Medicine*, 35(4):287-98, 2005.

19. Xu X, Werner J. A dynamic model of the human/clothing/environment-system. *Applied Human Sciences,* 16(2):61-75,1997.

20. Xu X, Rioux TP, Gonzalez J, Hansen EO, Castellani JW, Santee WR, et al. A digital tool for prevention and management of cold weather injuries—Cold Weather Ensemble Decision Aid (CoWEDA). *International Journal of Biometeorology*,1-12, 2021.

21. Xu X, Rioux T, Gonzalez J, Hansen E, Castellani J, Santee W, et al. Development of a cold injury prevention tool: The Cold Weather Ensemble Decision Aid (CoWEDA). US Army Research Institute of Environmental Medicine, Natick, MA, 01760, USA, Technical Report, T19-06, 2019.

22. Castellani JW, Young AJ, Ducharme MB, Giesbrecht G, Glickman EL, Sallis RE. Prevention of cold injuries during exercise. *Medicine & Science in Sports & Exercise*, (38):11-2012, 2006.

23. Hao X, Zhang J, Guo Y. Study of new protective clothing against SARS using semi-permeable PTFE/PU membrane. *European Polymer Journal*, 40(4):673-8, 2004.

24. Kuklane K, Lundgren K, Gao C, Löndahl J, Hornyanszky ED, Östergren P-O, et al. Ebola: improving the design of protective clothing for emergency workers allows them to better cope with heat stress and help to contain the epidemic. *Annals of Occupational Hygiene*, 59(2):258-61, 2015.

25. MacMahon KL, Delaney LJ, Kullman G, Gibbins JD, Decker J, Kiefer MJ. Protecting poultry workers from exposure to avian influenza viruses. *Public Health Reports*,123(3):316-22, 2008.

26. Wong TK, Chung JW, Li Y, Chan WF, Ching PT, Lam CH, et al. Effective personal protective clothing for health care workers attending patients with severe acute respiratory syndrome. *American Journal of Infection Control*, 32(2):90-6, 2004.

27. Coca A, Quinn T, Kim J-H, Wu T, Powell J, Roberge R, et al. Physiological evaluation of personal protective ensembles recommended for use in West Africa. *Disaster Medicine and Public Health Preparedness*, 11(5):580-6, 2017.

28. Xu X, Endrusick TL, Laprise BS, Santee WR, Kolka MA. Efficiency of liquid cooling garments prediction and manikin measurement. *Aviation, Space and Environmental Medicine,* 77(6):644-8, 2006.

29. Potter AW, Blanchard LA, Gonzalez JA, Salmeron JC, Cadarette BS, Luippold AJ, et al. Comparison of the biophysical properties and simulated performance of two cooling vests. US Army Research Institute of Environmental Medicine, Natick, MA, 01760, USA, Technial Report, T21-04, 2021

30. Cadarette BS, Latzka WA, Levine L, Sawka MN. A physiological evaluation of a prototype air-vest microclimate cooling system. US Army Research Institute of Environmental Medicine, Natick, MA, 01760, USA, Technial Report, T14-91, 1991.

31. Cadarette BS, Levine L, Kolka MA, Proulx GN, Correa MM, Sawka MN. Heat strain reduction by ice-based and vapor compression liquid cooling systems with a toxic agent protective uniform. *Aviation, Space and Environmental Medicine,* 73(7):665-72, 2002.

32. Cadarette B, Chinevere TD, Ely BR, Goodman DA, Laprise BS, Teal W, et al. Physiological responses to exercise-heat stress with prototype pulsed microclimate cooling system. Technical Report, T08-12, 2008.