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BIOPHYSICAL ASSESSMENT OF THE US ARMY IMPROVED HOT WEATHER COMBAT UNIFORM (IHWCU) AND A COMPARISON TO THE CURRENTLY FIELDED FIRE RESISTANT ARMY COMBAT UNIFORM (FRACU)

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BIOPHYSICAL ASSESSMENT OF THE US ARMY IMPROVED HOT WEATHER COMBAT UNIFORM (IHWCU) AND A COMPARISON TO THE CURRENTLY FIELDED FIRE RESISTANT ARMY COMBAT UNIFORM (FRACU)

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14. ABSTRACT
New uniforms have been developed specifically for hot and humid environments. Methods: Standard tests for the thermal and evaporative resistances (Rt and Ret) were conducted (ASTM F1291-16 & ASTM F2370-16) for two US Army uniforms, the new Improved Hot Weather Combat Uniform (IHWCU) and the currently fielded Fire Resistant Army Combat Uniform (FRACU). Results: Standard biophysical test values were similar between the two ensembles (IHWCU, FRACU) for thermal insulation 1.44 and 1.40 (clo), vapor permeability (im) (0.40 and 0.43), and evaporative potential (im/clo) (0.29 and 0.32) in near-still air conditions (0.4 ms-1 wind velocity). The modeling values for these measures (1.0 ms-1 wind velocity) were nearly identical; 1.11 and 1.11 clo, 0.41 and 0.45 im, and 0.37 and 0.37 im/clo. Conclusion: This work provides some quantitative evidence that the thermal properties of these two ensembles are similar and that from a biophysical perspective there are negligible differences between them.

15. SUBJECT TERMS
thermal manikins; biophysics; clothing; predictive modeling; thermoregulation

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TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

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EXECUTIVE SUMMARY

Introduction: Dismounted Soldiers are commonly required to perform highly demanding physical tasks within a variety of environmental conditions during both training and operational missions. There is a continued goal to optimize Warfighter performance by providing them with the clothing and individual equipment that is durable, lightweight, and reduces their imposed thermal strain. To this end, new uniforms have been developed specifically for hot and humid environments. This work provides a cost effective and scientifically valid method of making comparisons of clothing and equipment changes prior to conducting human research. **Methods:** Standard tests for the thermal and evaporative resistances (R_t and R_{et}) were conducted (ASTM F1291-16 & ASTM F2370-16) for two US Army uniforms, the new Improved Hot Weather Combat Uniform (IHWCU) and the currently fielded Fire Resistant Army Combat Uniform (FRACU). **Results:** Standard biophysical test values were similar between the two ensembles (IHWCU, FRACU) for thermal insulation 1.44 and 1.40 (clo), vapor permeability (i_m) (0.40 and 0.43), and evaporative potential (i_m/clo) (0.29 and 0.32) in near-still air conditions (0.4 ms^{-1} wind velocity). The modeling values for these measures (1.0 ms^{-1} wind velocity) were nearly identical; 1.11 and 1.11 clo, 0.41 and 0.45 i_m, and 0.37 and 0.37 i_m/clo. **Discussion:** The tests and predictive modeling shows there are relatively negligible differences between the two clothing ensembles from a thermal burden perspective. However, follow-on work may be investigated to find out if there are any human factors related differences that prove beneficial (e.g., thermal comfort, durability, etc.). **Conclusion**: This work provides some quantitative evidence that the thermal properties of these two ensembles are similar and that from a biophysical perspective there are negligible differences between them.

INTRODUCTION

Dismounted Soldiers are commonly required to perform highly demanding physical tasks within a variety of environmental conditions during both training and operational missions. There is a continued goal to optimize Warfighter performance by providing them with the clothing and individual equipment that is durable, lightweight, and reduces their imposed thermal strain. To this end, new uniforms have been developed specifically for hot and humid environments.

This report provides: 1) a quantitative assessment of the biophysical properties of the new US Army Improved Hot Weather Combat Uniform (IHWCU), 2) a comparison to current US Army Fire Resistant Army Combat Uniform (FRACU), and 3) a mathematical analysis of predicted thermophysiological impacts between the two configurations in a simulated hot and humid (jungle) environment. This work provides a cost effective and scientifically valid method of making comparisons of clothing and equipment changes prior to conducting human research.

METHODS

Standard tests for the thermal and evaporative resistances (R_t and R_{et}) were conducted (ASTM F1291-16 & ASTM F2370-16) for two US Army uniforms, the new Improved Hot Weather Combat Uniform (IHWCU) and the currently fielded Fire Resistant Army Combat Uniform (FRACU). These measured values were used as inputs into a predictive model [1-2] to simulate physiological responses to a hot-humid (jungle) environment.

Ensembles

Two full uniform ensembles were tested: the Improved Hot Weather Combat Uniform (IHWCU) and the Fire Resistant Army Combat Uniform (FRACU). Both ensembles were tested over a standard issue tan cotton t-shirt, cotton briefs, green cotton socks, and the hot weather desert tan suede combat boots (Figure 1).

Figure 1. Thermal manikin dressed in the Improved Hot Weather Combat Uniform (IHWCU), left and Fire Resistant Army Combat Uniform (FRACU), right.

IHWCU FRACU

Biophysical Testing

Biophysical assessments were conducted using a twenty zone sweating thermal manikin ('Newton' 20 Zone, Thermetrics, Seattle, WA http://www.thermetrics.com/) within a climate-controlled wind tunnel. Tests were conducted for thermal and evaporative resistance (R_t and R_{et}) according to American Society for Testing and Materials (ASTM) standards F1291-16 and F2370-16 [1-2]. These values were then converted to measures of total thermal insulation (I_T) in units of clo, a water vapor permeability index (i_m), and a ratio of these two parameters describe the ensembles evaporative potential (i_m/clo) [3-4].

In accordance with ASTM standards, both thermal resistance (R_t) and evaporative resistance (R_{et}) were tested under controlled conditions. Chamber conditions for R_t were: air temperature (T_a) 20°C, 50% relative humidity (RH), wind velocity (V) 0.4 ms^{-1} (set by fan speed), manikin surface [skin] temperature (T_s) was set at 35°C. To ensure an acceptable thermal gradient, a temperature difference of 15°C between T_s and T_a was used to assess sensible (dry) heat exchange. Power (W) used to maintain the T_s at 35°C was used to calculate the R_t of each clothing ensemble. For the measurement of R_{et}, both T_a and T_s were set to 35°C, the chamber was set to 40% RH, and a V of 0.4 ms^{-1}. Having T_a and T_s set to the same temperature, ensures all (meaningful majority) of heat loss can be ascribed to evaporative (insensible / wet) heat exchange, enabling a measure of R_{et}.

Testing for both measurements were conducted at three wind velocities (*V*) to enable the calculation of coefficient (gamma) values (^{g}) to describe the change in insulation and evaporative potential with increasing wind speeds [5-7]. To ensure repeatability, tests were replicated three times at each of the environmental conditions for a total of 18 tests per ensemble (9 for both R_t and R_{et}). These physical properties alone have comparative value [8] but can be interpreted and translated to human responses using modeling [9-10].

Predictive Modeling

Modeling and simulation of predicted human thermophysiological responses was conducted using USARIEM's Heat Strain Decision Aid (HSDA) [11-12]. A 'Standard male' was used for the simulation, where inputs included: a 20 year old healthy male, 70 kg, 172 cm tall, normally hydrated (-1.24%), heat acclimatized (12 days), and with initial core body and skin temperatures of 37 and 33°C. A hot-humid (jungle) simulated environment was used: 35°C; 75% RH, at sea level, an average wind velocity (*V*) of 1.0 ms^{-1}. Three work intensities were used to simulate standing at rest and walking at a speed of 1.34 ms^{-1} (3 mph) on 3% grade for two load conditions (34 and 44kg); these three inputs were calculated as 110, 331, and 364 watts Metabolic costs of walking were estimated using improved USARIEM metabolic modeling methods [13-18].

RESULTS

Biophysical Assessments

The total thermal insulation (I_T, clo) (Figure 2), vapor permeability (i_m) (Figure 3), and evaporative potential (i_m/clo) (Figure 4) of each configuration measured at different wind velocities are shown in Figures 2-4. These measured values along with their wind velocities coefficient values were generally similar (Table 1).

Table 1. Total thermal resistance (I_T, clo), permeability indices (i_m) and evaporative potential (i_m/clo) at wind velocities (*V*) of 0.4 and 1.0 ms^{-1} and wind velocity coefficients (^{g}) for both.

	***V*: 0.4 ms^{-1} Standard Measure (via ASTM [REFs])**			***V*: 1.0 ms^{-1} Measure used for modeling**			**Wind Velocity Coefficients**	
	clo	**i_m**	**i_m/clo**	**clo**	**i_m**	**i_m/clo**	**clo ^{g}**	**i_m/clo ^{g}**
IHWCU	1.44	0.40	0.29	1.11	0.41	0.37	-0.288	0.329
FRACU	1.40	0.43	0.32	1.11	0.45	0.37	-0.253	0.304

Figure 2. Total thermal (I_T, clo) for both the Improved Hot Weather Combat Uniform (IHWCU) and Fire Resistant Army Combat Uniform (FRACU)

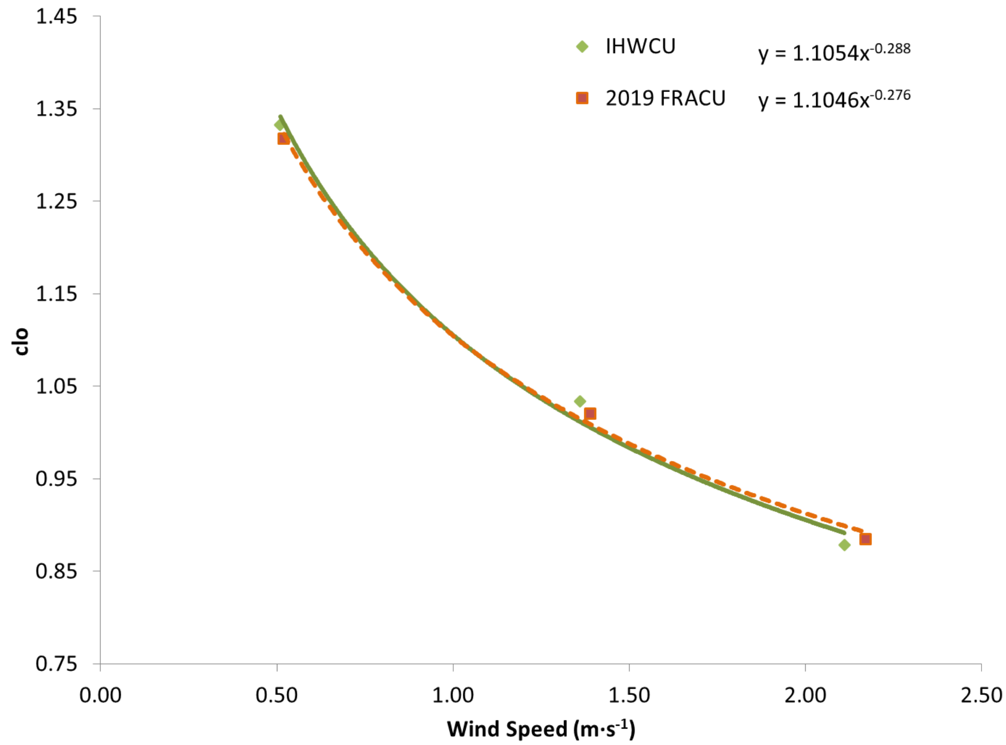


Figure 3. Vapor permeability indices (i_m) for both the Improved Hot Weather Combat Uniform (IHWCU) and Fire Resistant Army Combat Uniform (FRACU)

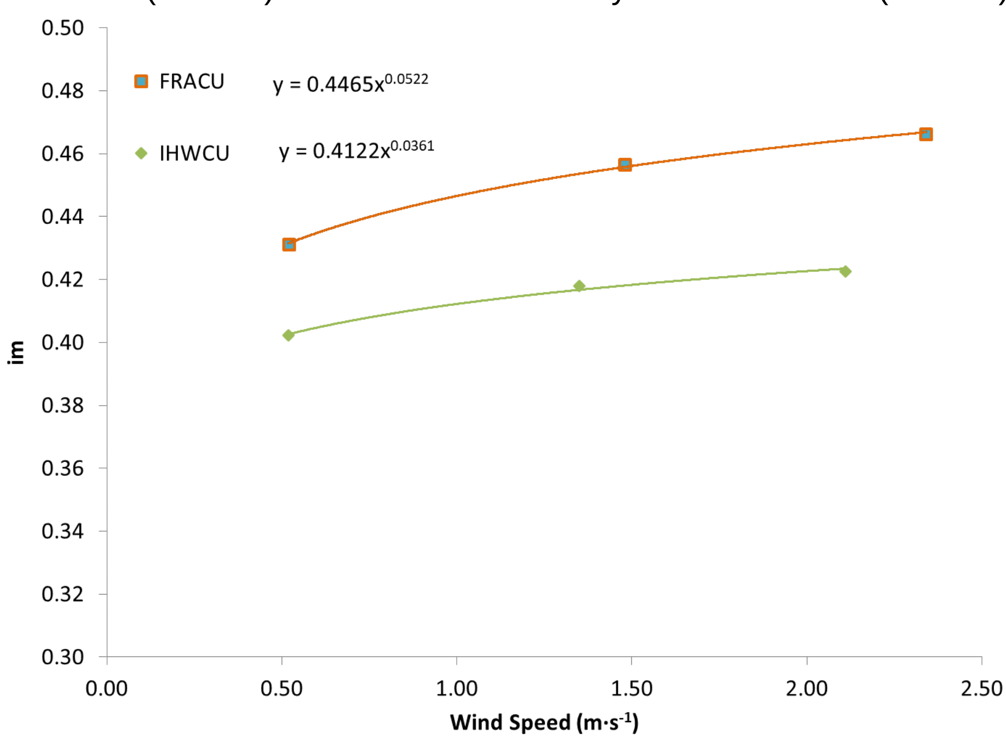
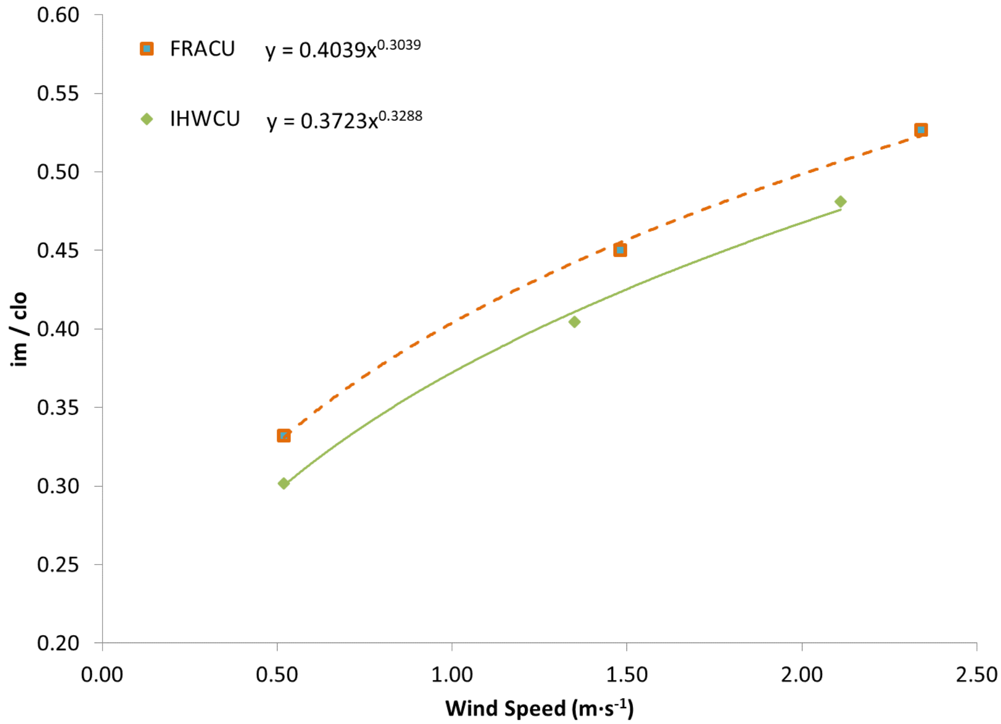


Figure 4. Evaporative potential (i_m/clo) for both the Improved Hot Weather Combat Uniform (IHWCU) and Fire Resistant Army Combat Uniform (FRACU)



Predictive Modeling

Modeling and simulations for each conditions showed very minimal differences in predicted responses in core body temperature based on clothing ensemble (Figures 5-7). In the standing condition there was no observable [meaningful] difference in the rise of core body temperature (Figure 5). In both of the walking conditions (Figure 6-7) very minor differences can be seen, where the IHWCU has a higher rate or rise in core body temperature compared to the FRACU. While minor differences can be observed between predicted increases in core body temperature between the IHWCU and FRACU; these differences occur mostly after or near critical temperature levels (i.e., ≥38.5 °C) (Figures 5 – 7). Additionally, these differences should be considered as negligible or within the accepted room of error for the predictions.

Figure 5. Predicted core temperature (T_c, °C) over 120 minutes while standing in a hot-humid environment wearing the Improved Hot Weather Combat Uniform (IHWCU) and Fire Resistant Army Combat Uniform (FRACU)

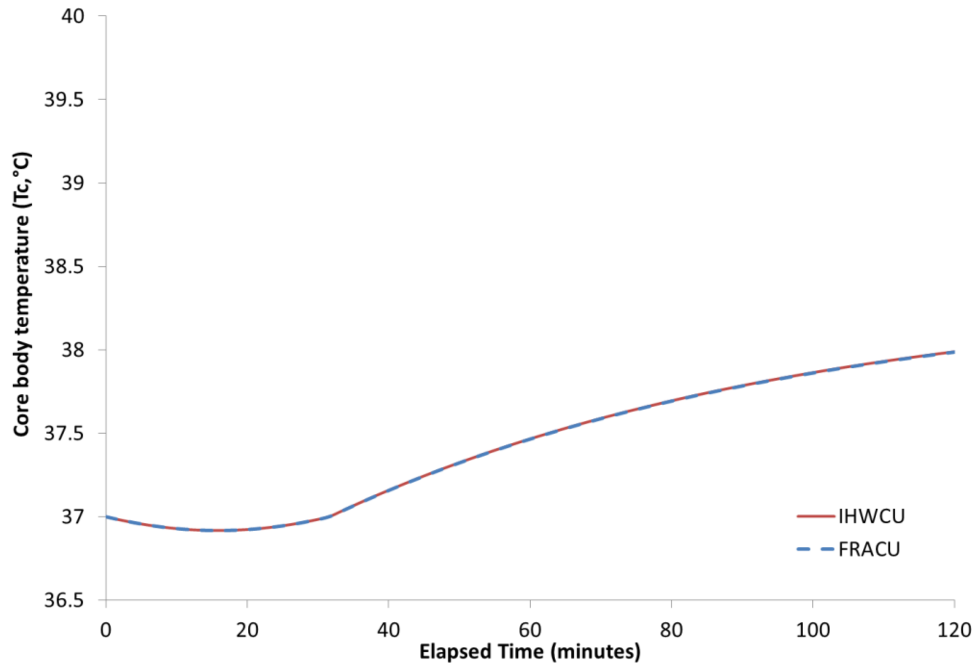


Figure 6. Predicted core temperature (T_c, °C) over 120 minutes while walking 1.34 ms^{-1} carrying a 34 kg load in a hot-humid environment wearing the Improved Hot Weather Combat Uniform (IHWCU) and Fire Resistant Army Combat Uniform (FRACU)

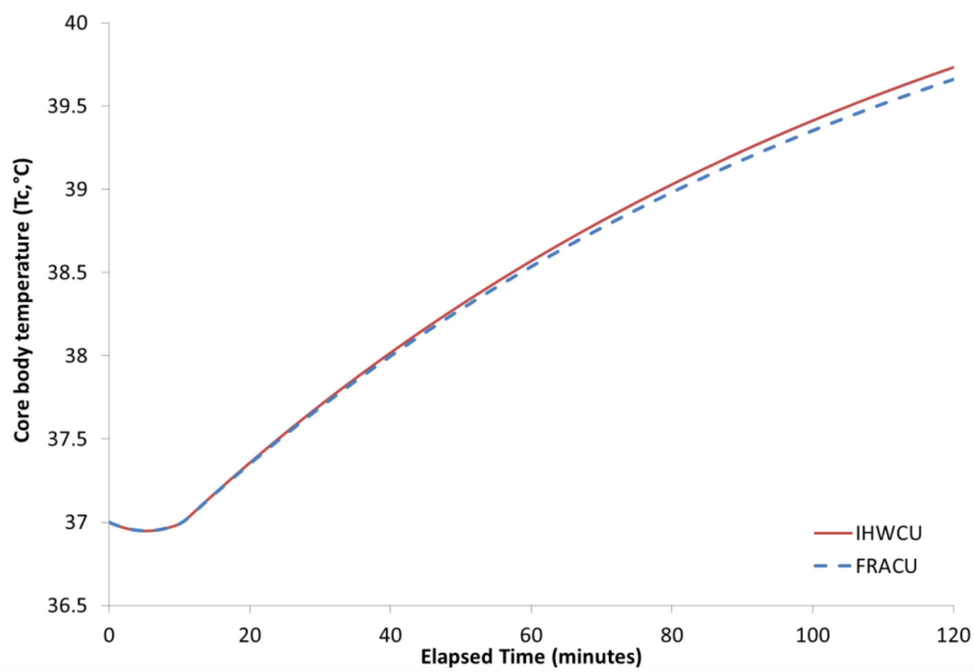
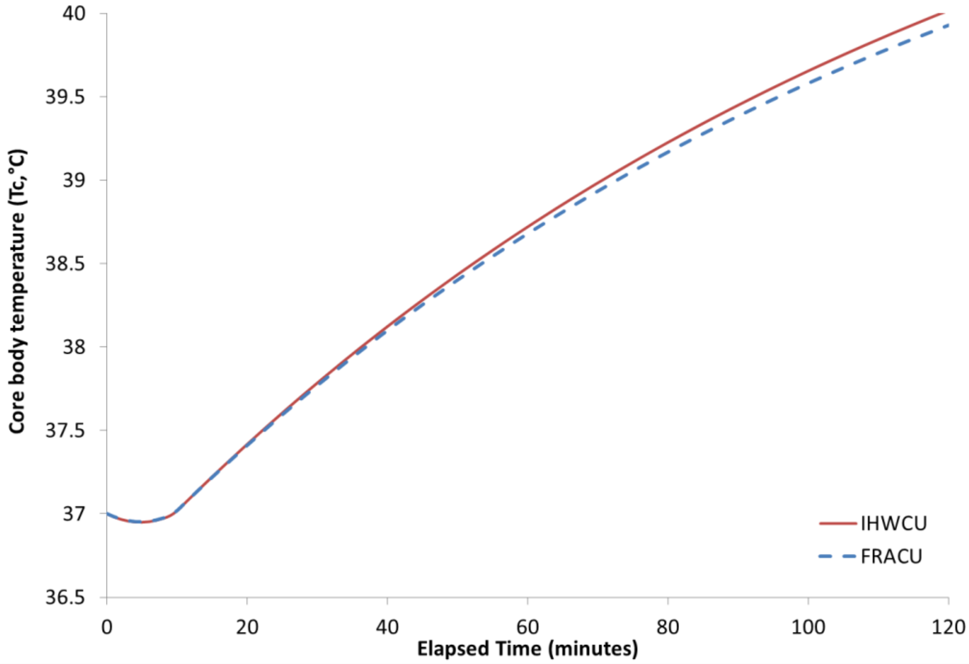


Figure 7. Predicted core temperature (T_c, °C) over 120 minutes while walking 1.34 ms^{-1} carrying a 44 kg load in a hot-humid environment wearing the Improved Hot Weather Combat Uniform (IHWCU) and Fire Resistant Army Combat Uniform (FRACU)



DISCUSSION

Using a combination of thermal manikin biophysical assessments along with predictive modeling and simulation provide meaningful and cost effective approaches to clothing assessments. However, as there are limitations to elements within these simulations and modeling methods, human factors assessments and human field studies are still a required step in studying the full effects and influences of clothing systems. Human research studies collecting relevant physiological data can be extremely helpful in sorting out human factors issues as well as for validating and improving existing models [19-23]. Additionally, field and laboratory studies collecting a wider range of environmental conditions allow for model improvements that expand the scope of use that these modeling and simulation methods can be applied with validity. Thus allowing for customized empirically- or rational-derived modeling approaches to determine safe stay times in enclosed spaces (e.g., aircraft, vehicles, buildings) [24-27] or for complex environments such as submarines or subterranean [28].

This work provides some quantitative evidence that the thermal properties of these two ensembles are similar and that from a biophysical perspective there are negligible differences between them. Further human-based studies are needed for real-world validation of these findings.

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