FLORIDA STATE UNIVERSITY
JIM MORAN COLLEGE OF ENTREPRENEURSHIP

ThermaNOLE Comfort Lab®

Test Report

Issued to **Fire-Dex, LLC**

on **April 18th, 2024**

regarding the **Manikin Physiological Control (Manikin PC) Testing**

of **Structural Firefighter Turnout Suits**

on an **ANDI Dynamic Sweating Thermal Manikin**

Issued by **Florida State University**

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TESTING SCOPE OF WORK

Fire-Dex submitted five structural firefighter turnout suits (coat and pants) to the ThermaNOLE Comfort Lab™ in the Jim Moran College of Entrepreneurship at Florida State University. An advanced dynamic thermal physiological manikin with a Manikin PC (physiological comfort) plugin model was utilized to assess the real time physiological responses of each warming device. The purpose of this document is to describe the samples tested, procedures used, and the results collected from the laboratory tests.

Sample Description

Turnout suits (Appendix B) were tested on an ANDI sweating thermal manikin, as detailed in Table 1 below. Each suit ensemble tested included the turnout coat and pants, provided by the client; the following base layers: athletic shorts, short sleeve cotton t-shirt, and socks; and the following ensemble elements: boots, gloves, single layer knit hood, and helmet. The cotton shirt was tucked into the shorts. Three replicate tests were run on each suit for the entire custom ManikinPC active human thermoregulation testing protocol in a dynamic state (manikin walking; 0.4 m/s still air speed).

Table 1. Test Ensembles

Suit	Description	Size
Suit 1 (FXR Control)	OS: PBI 7oz Max MB: Crosstech® Black Type 2F ePTFE membrane TL: Glide ICE™ 2-Layer Aramid/Viscose	Coat: 36/32/31 Pant: 32/29
Suit 2 (FX1)	OS: PBI 7 oz Max 7oz + TG71 RET zone MB: Crosstech® Black Type 2F ePTFE membrane with vents TL: Glide ICE™ 2-Layer Aramid/Viscose + Core CXP 1 Layer RET zone with Vents	Coat: 36/32/31 Pant: 32/29

ANDI Sweating Thermal Manikin System

An "ANDI" instrument is an articulated 35-zone sweating thermal manikin system designed to evaluate heat and moisture management properties of clothing systems. This instrument simulates heat and sweat production making it possible to assess the influence of clothing on the thermal comfort process for a given environment. Simultaneous heat and moisture transport through the clothing system, and variations in these properties over different parts of the body can be quantified. The manikin consists of several features designed to work together to evaluate clothing comfort and/or heat stress. Housed in a climate-controlled chamber (Figure 1), the manikin surface is divided into 35 separate zones, each of which has its own sweating, heating, and temperature measuring system. Except for a small portion of the face, the entire manikin surface can continuously sweat.

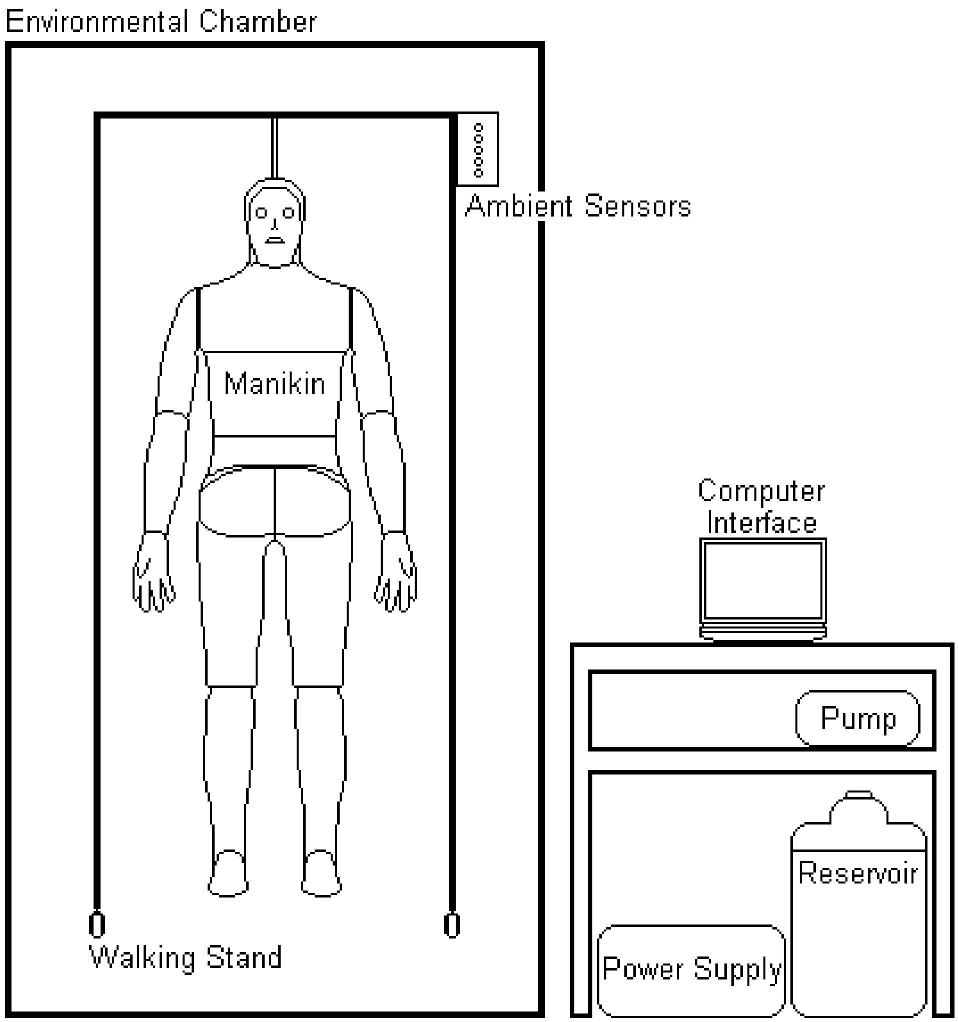

Figure 1. Test Apparatus Setup

Using a pump, preheated water is supplied from a reservoir located outside of the environmental chamber. An internal sweat control system distributes moisture to 140 "sweat glands" distributed across the surface of the manikin. Water supplied to the simulated sweat glands is controlled by operator entry of the desired sweat rate. Each sweat gland is individually calibrated, and the calibration values are used by the control software to maintain the sweat rate of each body section.

Water exuding from each simulated sweat gland is absorbed by a custom-made body suit (known as a “sweating skin” system). This specially designed suit acts as the manikin’s ‘skin’ during sweating tests. It is form-fitted to the manikin to eliminate air gaps and provides wicking action to evenly distribute moisture across the entire manikin surface.

Continuous temperature control for the 35 body segments is accomplished by a process control unit that uses analog signal inputs from separate Resistance Temperature Detectors (RTDs). These evenly distributed RTDs are used instead of point sensors because they provide temperature measurements in a manner such that all areas are equally weighted. Distributed over an entire section, each RTD is embedded just below the surface and provides an average temperature for each section. Software establishes any discrepancy between temperature set point and the input signal and adjusts power to section heaters as needed. Temperature controls are adjustable, by the operator, for each heater control. Figure 2 illustrates the 35 zones of the ANDI manikin. Additional options exclusive to ANDI include dynamic heat flux sensing and active cooling channels which allow the manikin to be used in high ambient temperatures and in positive or negative heat flux environments.

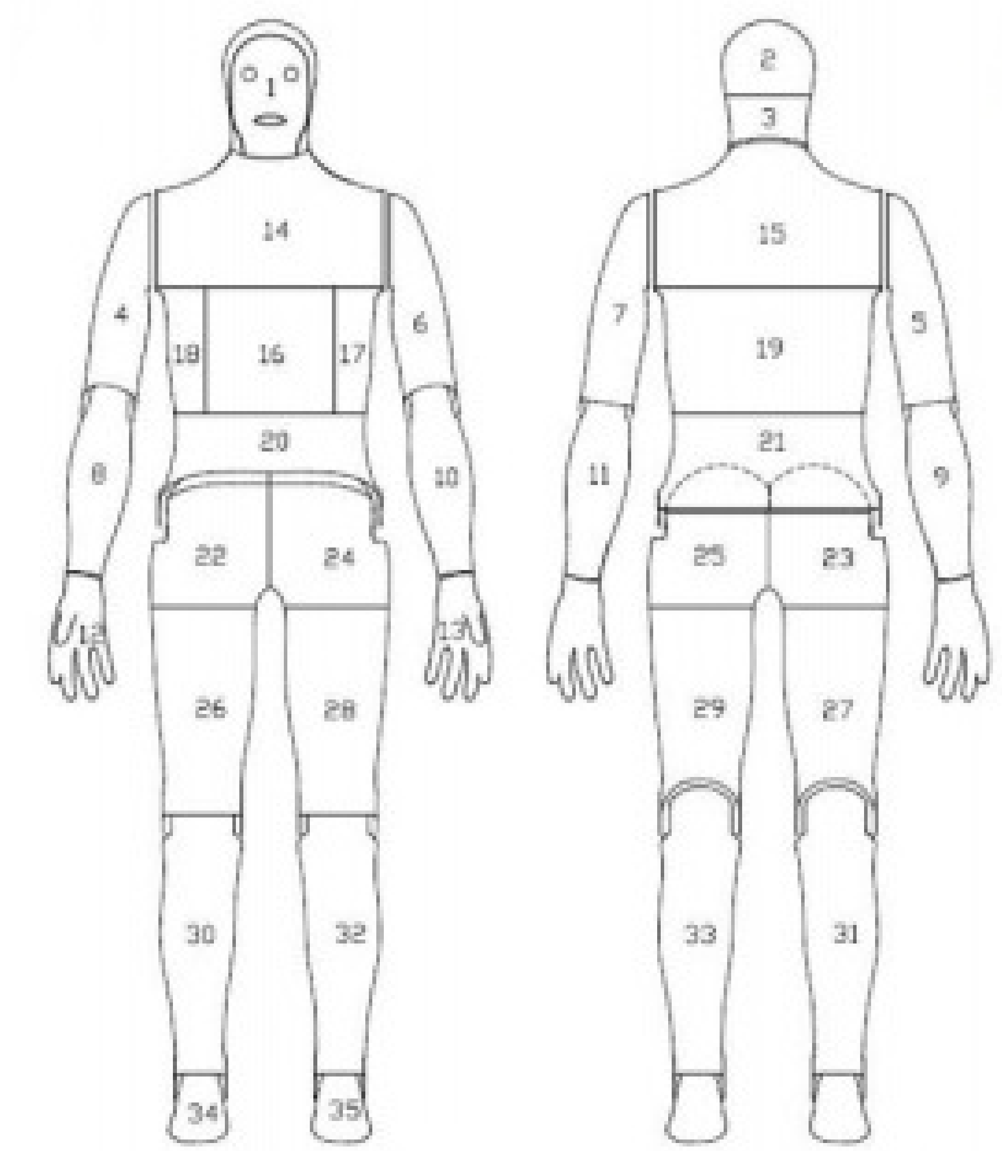

Figure 2. A schematic of the 35 Zone ANDI Manikin

Manikin PC² Physiological Model Control

ManikinPC² is integrated with the ANDI sweating thermal manikin system which is intended to simulate the human body's active thermoregulation. It computes the thermal state of a simulated human and provides real-time predictions of human physiological responses, comfort, and sensation in dynamically changing environments. ManikinPC² predicts average skin temperature, surface temperature, core body temperature, sweat rates, skin blood flow, and other parameters (see Appendix A).

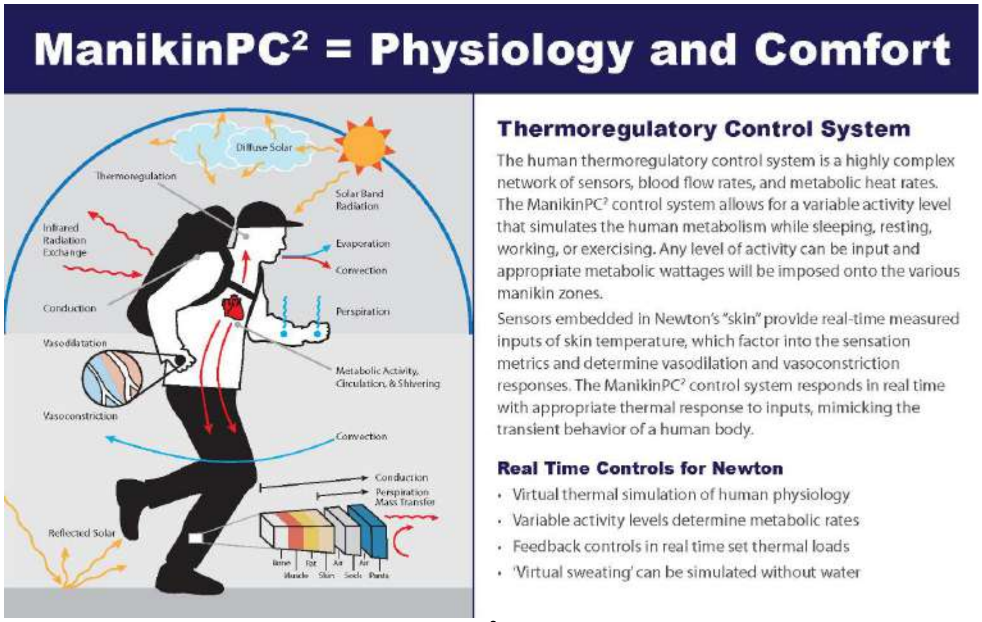

Figure 3. Schematic of ManikinPC^2 Thermoregulatory Control System

Testing Procedures

The purpose of this testing was to determine the modeled physiological responses (core temperature, skin temperature, sweat rate, perceived comfort, and perceived sensation, etc.) when wearing the turnout suits. Three test repetitions were performed on each turnout suit. The test protocol was based on previous human wear studies published in scientific literature and was determined after a week of pilot testing Suits 1 and 2 at two metabolic rates (6.8 and 8.0 METs) and different lengths of time (3 versus 4 work/rest cycles) using the physiological model control function of the manikin. Under ManikinPC, ANDI responds to the test environment via a proprietary human thermoregulation model which is based on the Wissler, Fiala, and Berkeley thermal comfort models. Table 2 provides the conditions and parameters under which the tests were conducted. Table 3 summarizes the step-by-step testing protocol.

Table 2. Testing Parameters

Parameter	Test Conditions
Position/Movement	Dynamic/Walking
Sweat Rate	Model Predicted
Manikin Mode	Physiological Model Control
Skin Temperature	Model Predicted
Heat Flux	Model Dependent: Metabolic Rate (MET)
Work/Rest Cycle	20 mins work (6.8 METs)/5 mins rest (1 MET)
Ambient Temperature	33°C
Chamber Relative Humidity	35%
Airflow	~0.4 m/s

Table 3. Test Protocol

Test Protocol
1. Dress manikin in sweating skin to evenly distribute water sent to manikin surface.
2. Run Model Initialization to set manikin to steady state conditions including thermal neutral temperature set point (33°C) and sweat flow set points for all zones.
3. Dress manikin in shirt, briefs, shorts, socks, turnout suit, hood, helmet, boots, and gloves.
4. Begin physiological model control at a metabolic work rate of 6.8 METs.
5. Record predicted physiological responses of the manikin for a test duration of three 20-minute work (6.8 Mets)/5-minute rest (1 Met) cycles for a total of 75 minutes.
6. End test.

TEST RESULTS

The average values for ΔTsk, ΔTre, and ΔThy at the end of the 70-minute protocol, as well as the average SBF, Comfort, and Sensation are reported in Table 4.

Table 4. ΔTsk, ΔTre, ΔThy, average Swa, Comfort, and Sensation

Ensemble	ΔTsk	ΔTre	ΔThy	Swa (g/min)	Comfort	Sensation
Suit 1	5.81°C	3.54°C	4.08°C	25.02	-3.46	2.08
Suit 2	5.66°C*	3.39°C*	3.95°C*	24.56*	-3.23*	2.04*

*indicates preferred predicted physiological comfort value

CONSIDERATIONS

The data obtained under controlled laboratory conditions characterize the predicted thermo-physiological responses under specific environmental conditions. These results should not be used to appraise the safety benefits or risks of the materials or products in extreme use conditions. The relationships between laboratory tests and field performance are complex and do not always practically translate. Clothing comfort is a complex phenomenon determined by many important factors including the garments worn, activity level, and environmental conditions. The results here within do not address the full range of factors regarding clothing comfort in all potential use scenarios. It is not the intention of Florida State University to recommend, exclude, or predict the suitability of any commercial product for a particular end use.

APPENDIX A: MODELED DATA DEFINITIONS

Predicted Hypothalamus Temperature (Thy)
There are two separate measures of core temperature in ManikinPC. The hypothalamus temperature is computed to be most representative of the respiratory, cardiac, and brain temperature.

Rectal Temperature (Tre)
The rectal temperature is simulated by the physiological model based on discrete thermal nodes in the gut of the physiology. This location and the corresponding thermal mass will provide more realistic response characteristics for comparison with human rectal or digestive (intestinal core temperature) system measurements.

Skin Temperature (Tsk)
Skin temperature for each region is read directly from the manikin and fed to the physiological model. The model calculates a whole body mean Tsk.

Active Sweating (Swa, Qswa)
Swa displays the amount of sweat generated by active thermoregulation in grams/min. The calculated volume is determined based on control equations in the model, which are functions of body core and skin temperature.

Comfort
Comfort is based on a scale of -4 (very uncomfortable) to 4 (very comfortable). 0 represents a "comfortable" state.

- Under any steady state conditions, the simulation will always return a value between -4 and 0 depending on if the manikin is too cold, too warm or "just right."
- Under dynamic conditions, the manikin may return positive values for comfort. One example is if the manikin is in a cold environment, but suddenly experiences a warm breeze. This represents a situation where the breeze produces a pleasant experience. These situations are always transient—if the breeze goes away, the manikin will be cold again. If the breeze goes on very long, the manikin will either return to neutral comfort or overheat.

When looking at manikin-wide comfort, certain zones are given greater weighting under certain conditions. In cold situations, body-wide comfort tends to track the comfort of the coldest extremity. In warm situations, it tracks the comfort of the head. This can be overridden if one particular zone experiences temperature extremes—in such a case, the affected zone(s) will dominate the comfort calculation.

Sensation
Sensation is a measure of how warm or cold the environment around the manikin feels relative to skin temperature; i.e., air that is slightly warmer than skin temperature will feel warm. Sensation is based on a scale of -4 to 4, where a value of 0 means the manikin "feels" no sensation of warm or cold. Positive values are warm to hot, negative values are cool to cold. Sensation is independent of comfort—a warm breeze can be either comfortable or uncomfortable depending on other ambient conditions.

APPENDIX B: Suits as Tested on ANDI Dynamic Thermal Manikin

Fire-Dex Suit Sample 1

Fire-Dex Suit Sample 2