A Report

to

**F.I.E.R.O**

on

**Phase II Testing: Predicted Physiological Responses from Eight Firefighting Suits Tested in Three Environmental Conditions**

**Report #PSM170626**

from

Textile Protection and Comfort Center (T-PACC)
College of Textiles
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Raleigh, North Carolina 27695-8301

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**Predicted Physiological Responses from Eight Firefighting Suits Tested in Three Environmental Conditions**

Eight firefighting garments were submitted to the Textile Protection and Comfort Center (TPACC) in the College of Textiles at North Carolina State University. These garments were tested on a thermal sweating manikin system coupled with a physiological model to predict an average human response during a simulated work protocol in three different environmental climates. All test garments were tested as received. The purpose of this report is to describe the test methods used to characterize these garments and to present the results of the laboratory tests.

This testing follows an initial investigation undertaken by F.I.E.R.O involving three different firefighting garment systems comprised of related composite materials. The goal of this testing was to compared manikin results to existing human physiological data. Information about Phase I testing (in the form of a presentation) can be found in Appendix A.

## Test Materials

Eight firefighting garments were tested with the physiological controlled manikin system. Each suit, manufactured by the same company, had identical construction but different fabric composites. Each suit was labeled **G1, G2, G3, G4, G5, G6, G7,** or **G8**. The evaporative resistance ($R_{et}$) and total heat loss ($Q_t$) values for the composites used in each suit can be found in Table 1. Details of each suit construction and composite can be found in Appendix B. Figure 1 displays one of the suits dressed on the manikin.

It should be noted that **G1, G2, G3, G4, G5** and **G6** were made of materials that were compliant with NFPA 1971 however, the suits themselves were not, as a DRD device was not incorporated into the coat. Garments **G7** and **G8** would not be compliant as they contain an impermeable membrane (**G7**) or no membrane at all (**G8**).

In addition to the firefighting garments, the manikin wore boxer briefs, a lightweight cotton t-shirt, socks, shoes, gloves, and helmet during testing. The cuffs of the pants were taped closed to limit heat escape in the attempt to replicate the same fit as if the manikin was wearing boots.

Prior to testing, garments and undergarments were placed in a 21$^{o}$C, 65% conditioned space.

Table 1: Test Materials

| **Sample** | $R_{et}$ | $Q_t$ |
|---|---|---|
| **G1** | **31.4** | **273.0** |
| **G2** | **26.9** | **254.6** |
| **G3** | **23.4** | **307.8** |
| **G4** | **21.8** | **256.8** |
| **G5** | **27.8** | **241.5** |
| **G6** | **27.6** | **246.5** |
| **G7** | **396*** | **101.9** |
| **G8** | **13.7** | **272.8** |

Figure 1.  Example of the Test Garments

## NCSU Sweating Thermal Manikin System

The NCSU sweating manikin system is a "Newton" type instrument 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 2), the manikin surface is divided into 34 separate sections, each of which has its own sweating, heating, and temperature measuring system. With the exception of a small portion of the face, the whole manikin surface can continuously sweat.

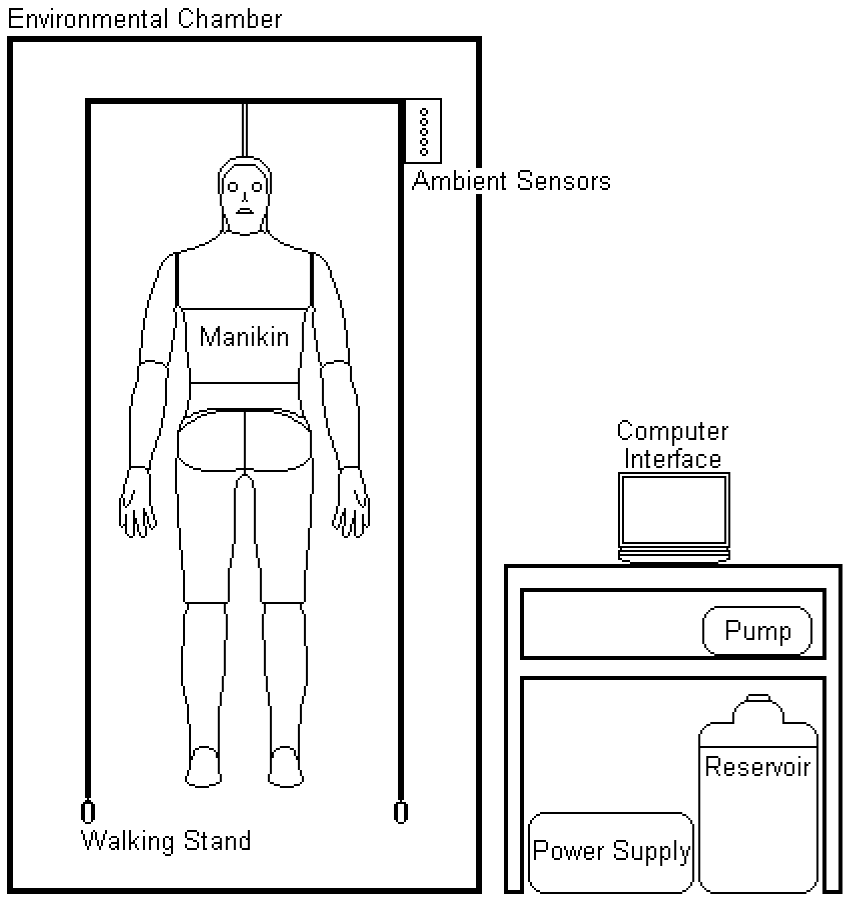



Figure 2. Test Arrangement

Using a pump, preheated water is supplied from a reservoir located outside of the environmental chamber. An internal sweat control system distributes moisture to 139 "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. This specialty 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 34 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.

## Manikin PC$^2$ Physiological Model Control

The Newton sweating manikin system combined with ManikinPC$^2$ (version 12.1.1) control system allows the manikin to simulate human metabolism and thermoregulation while performing a variety of activities. The software and manikin interact in real-time setting imitating the transient behavior of the human body and allowing for the most accurate predictions of human physiological response that can be achieved without actual human trials. The ManikinPC$^2$ model control system is used to predict human physiological response including average skin temperature, final temperature of each manikin section, predicted core body temperature, as well as other parameters.

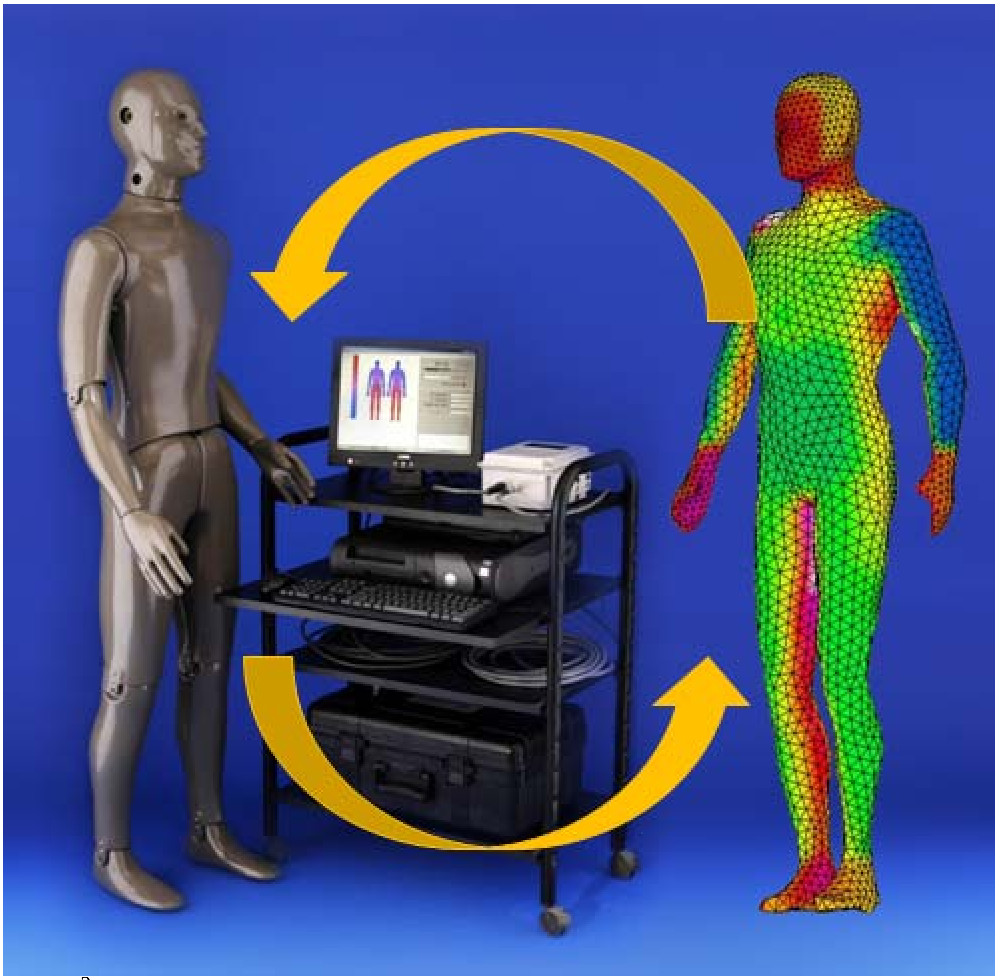


Figure 3. PC$^2$ System = Sweating Manikin Coupled with Thermoregulation Model Control

## Test Protocol

The purpose of this testing was to predicted the physiological response between eight firefighting garments with varying composites. Prior to testing the manikin was checked for leaks and then dressed with the sweating skin, undergarments and test garments. Each section of the manikin was then preheated to a thermo-neutral set point (Appendix C).

Once all temperatures were stable, the sweat rate of each zone of the manikin was set to 25 ml/(h·m$^2$) for 10 minutes while the manikin continued to maintain the thermo-neutral set point. This was done to prime the sweat pores and ensure that sweat would be available at the surface of the manikin at the start of the test. After 10 minutes had elapsed, the Manikin PC$^2$ software was started and the manikin was placed into one of the testing environments listed in Table 2.

While in the chamber, the manikin followed the protocol detailed in Table 3. When the manikin was assigned to sit, the manikin sat in a chair. When the manikin was simulating walking, the manikin was hooked up to the walking system and the number of double steps were applied to the system. The MET rates were manually entered into the program at the designated times. At the end of the test the garments were removed and dried on a Williams Direct Dryer. Data from the test was stored and plotted.

Table 2. Testing Conditions

| Test Condition | Temperature (°C) | Relative Humidity (%RH) | Air Flow (m/s) |
|---|---|---|---|
| 1 | 25 | 65 | 1.0 |
| 2 | 35 | 40 | 1.0 |
| 3 | 40 | 20 | 1.0 |

Table 3. Testing Protocol

| Time | Activity | Manikin position | MET rate | Walking speed |
|---|---|---|---|---|
| 0 | Enter chamber and resting | Sitting | 1 | 0 |
| 15 | Walking | Walking | 4.5 | 47dsm* |
| 40 | Resting | Sitting | 1 | 0 |
| 55 | Walking | Walking | 4.5 | 47dsm* |
| 80 | Resting | Sitting | 1 | 0 |
| 95 | Finish | NA | NA | NA |

*47 dsm is the setting on the manikin system equating to 47 double steps per minute. This is roughly the speed of walking 3.3 mph on a 1% incline.

## Test Results

Figures 4, 5 and 6 show the predicted core body temperature for the 25°C 65%RH, 35°C 40%RH, and 40°C 20%RH conditions respectively.

Figure 4. Predicted Core Body Temperature Response (25°C 65%RH Test Condition)

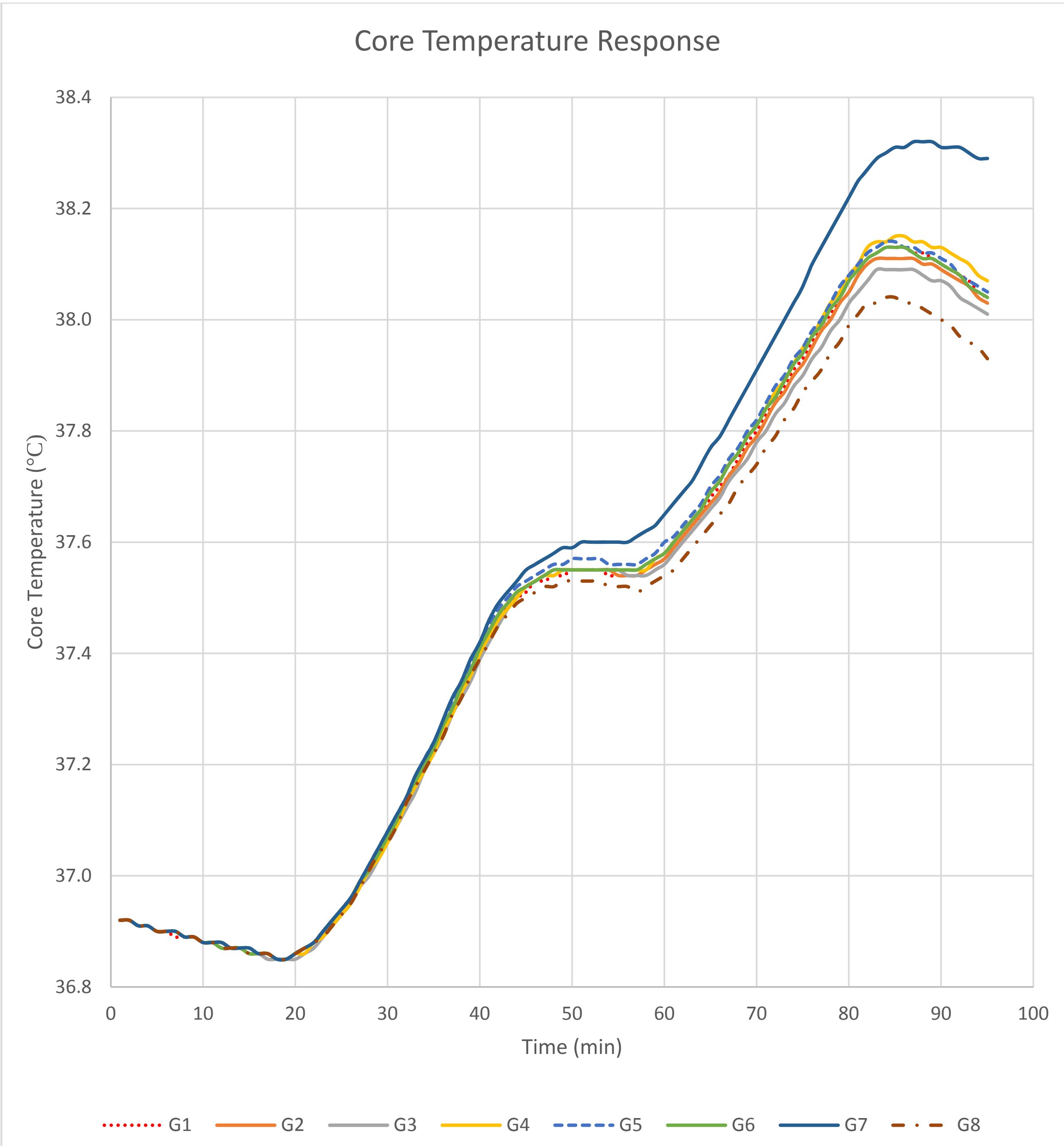


Figure 5. Predicted Core Body Temperature Response (35°C 40%RH Test Condition)

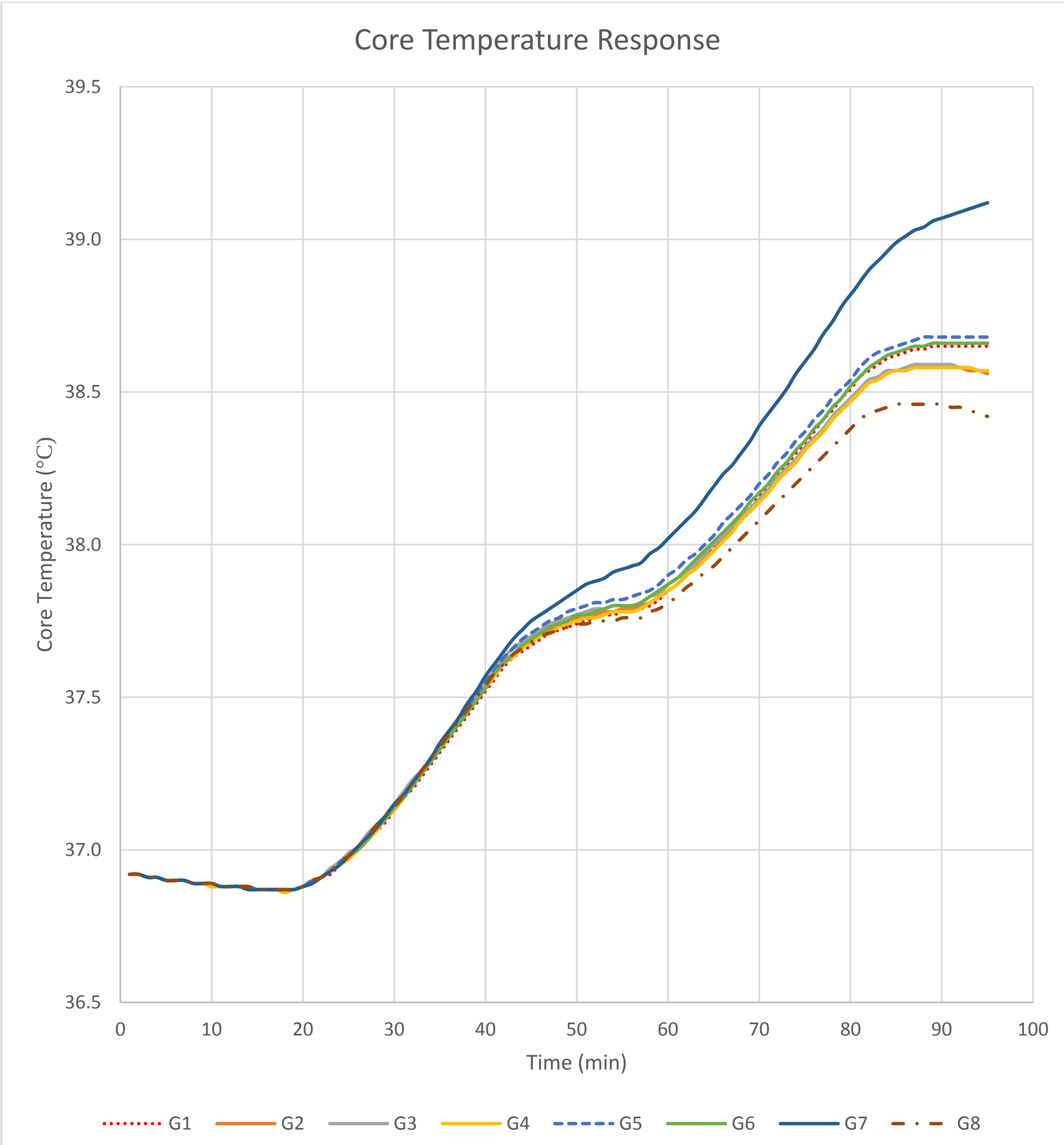
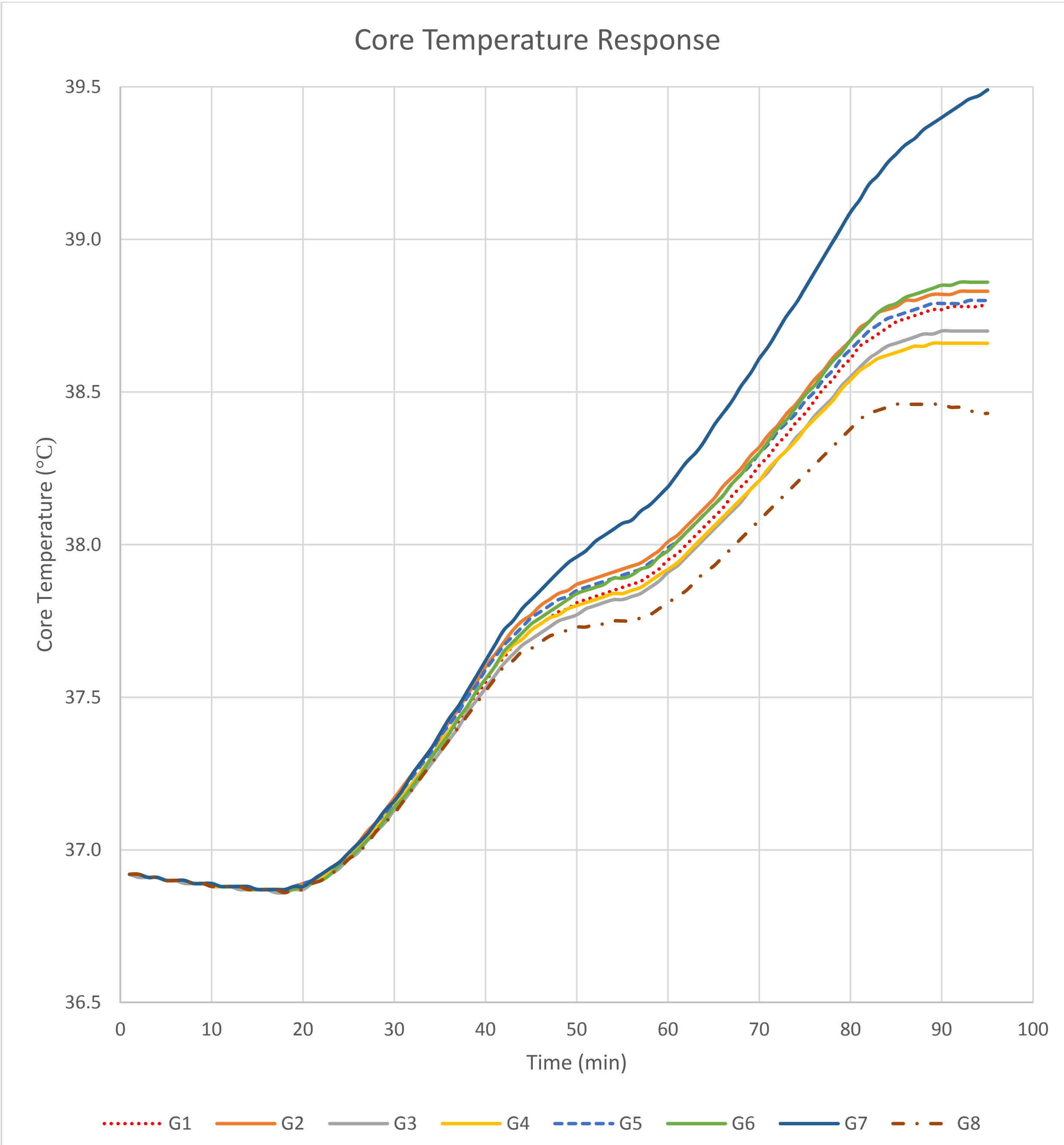


Figure 6: Predicted Core Body Temperature Response (40°C 20%RH Test Condition)



Figures 7, 8, and 9 show the predicted skin temperature for the 25°C 65%RH, 35°C 40%RH, and 40°C 20%RH conditions respectively.

Figure 7. Predicted Skin Temperature Response (25°C 65%RH Test Condition)

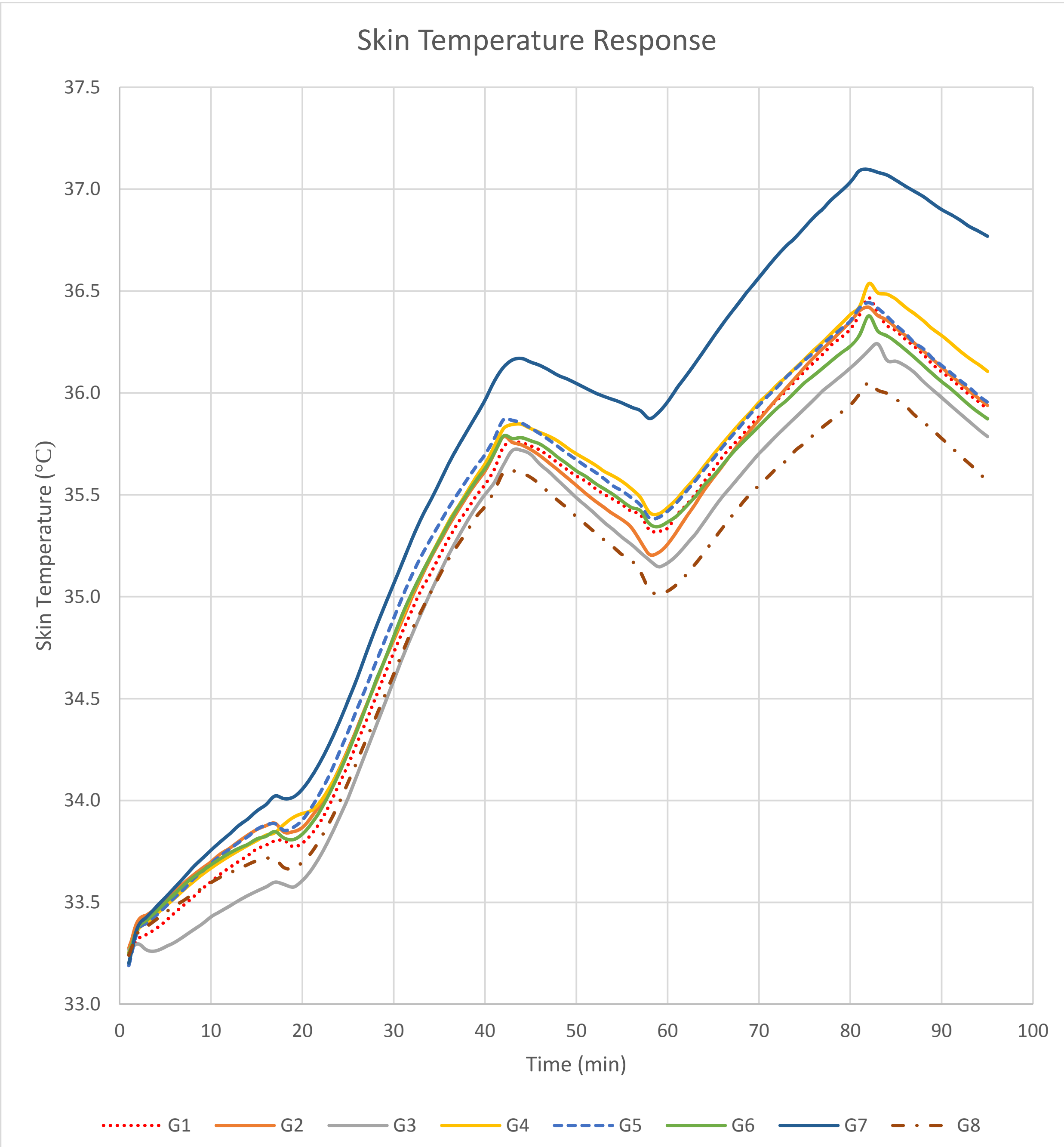


Figure 8. Predicted Skin Temperature Response (35°C 40%RH Test Condition)

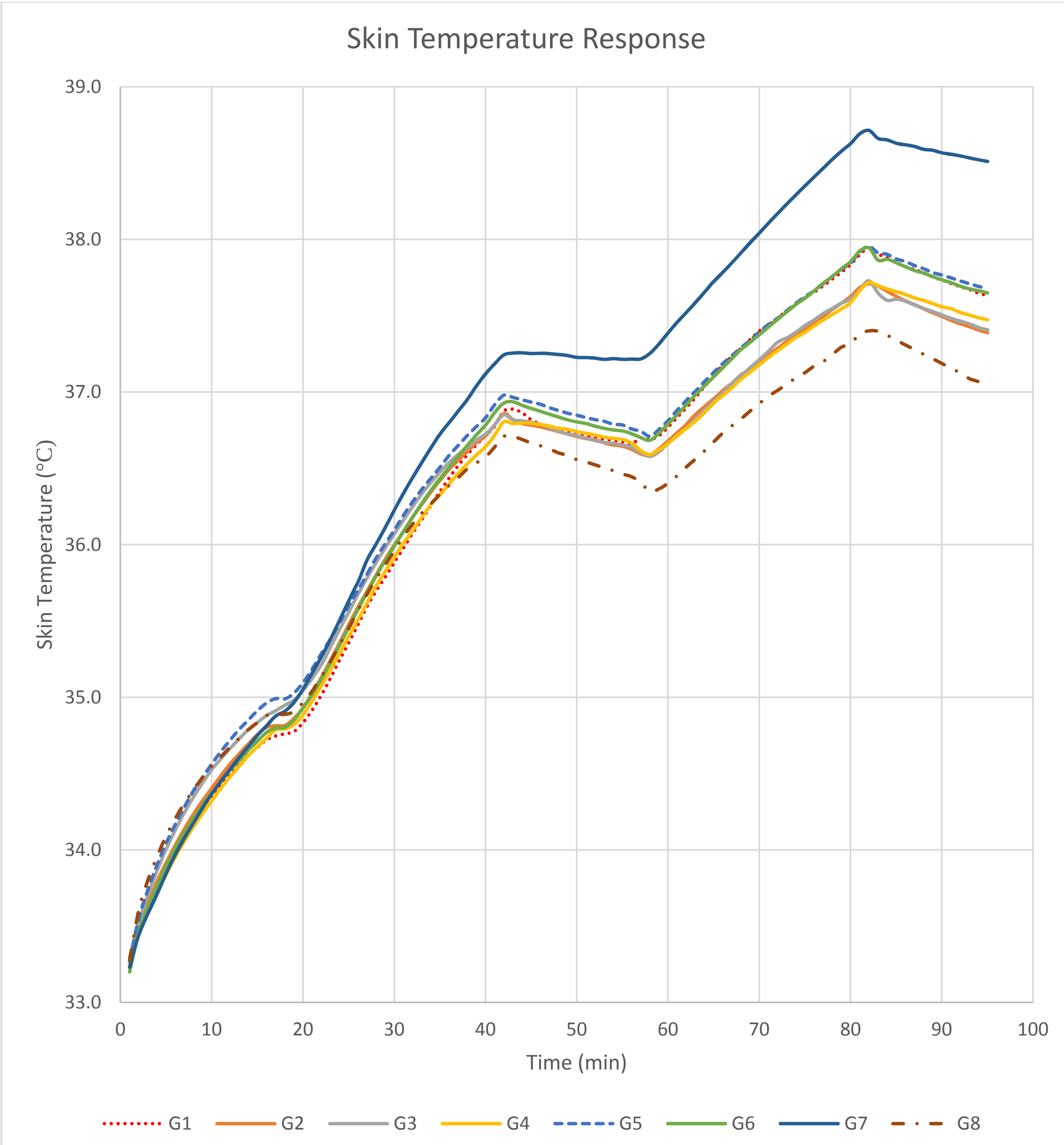
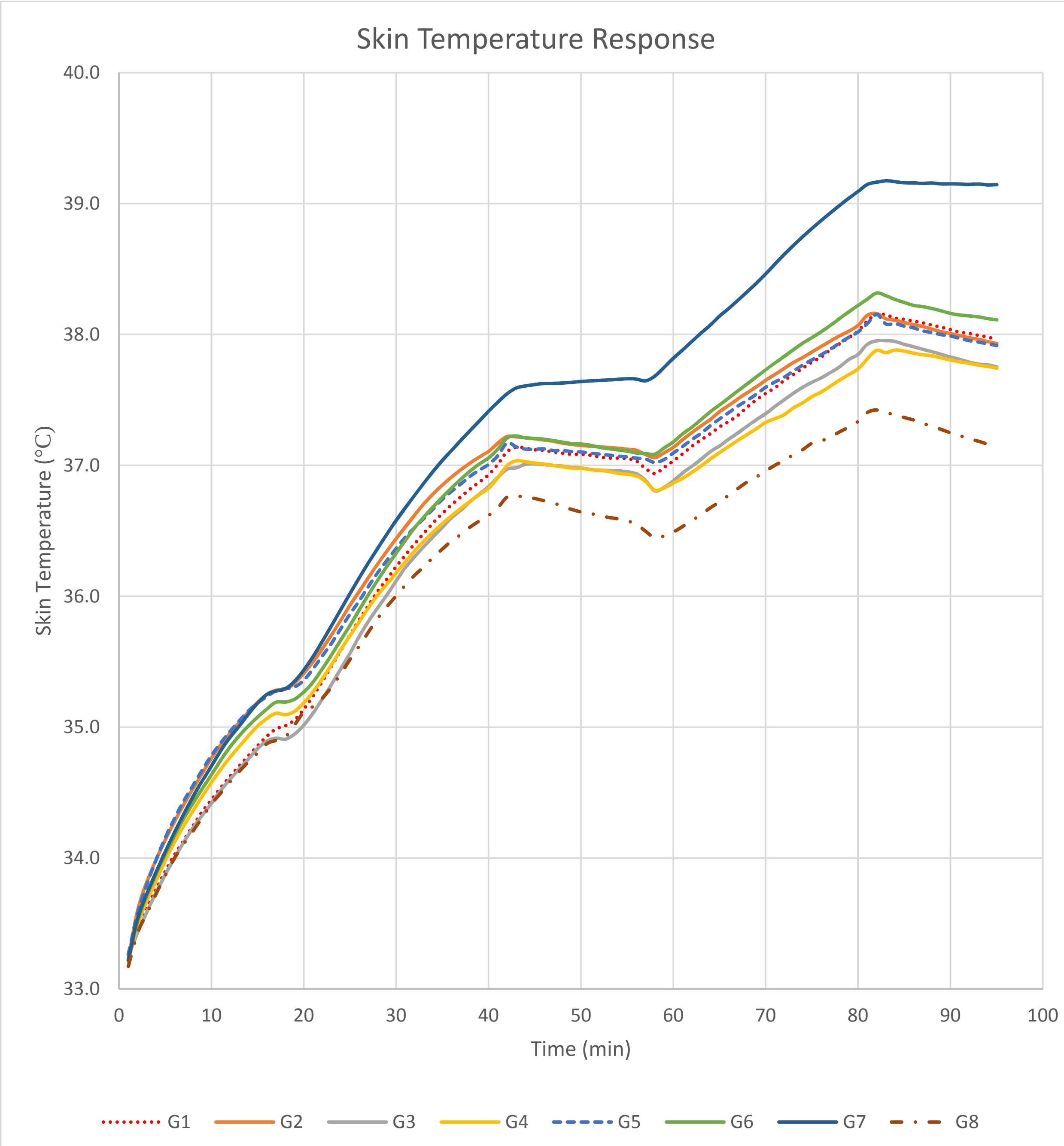


Figure 9. Predicted Skin Temperature Response (40°C 20%RH Test Condition)



Figures 10, 11, and 12 show the predicted sweat rate for the 25°C 65%RH, 35°C 40%RH, and 40°C 20%RH conditions respectively.

Figure 10. Predicted Sweat Rate Response (25°C 65%RH Test Condition)

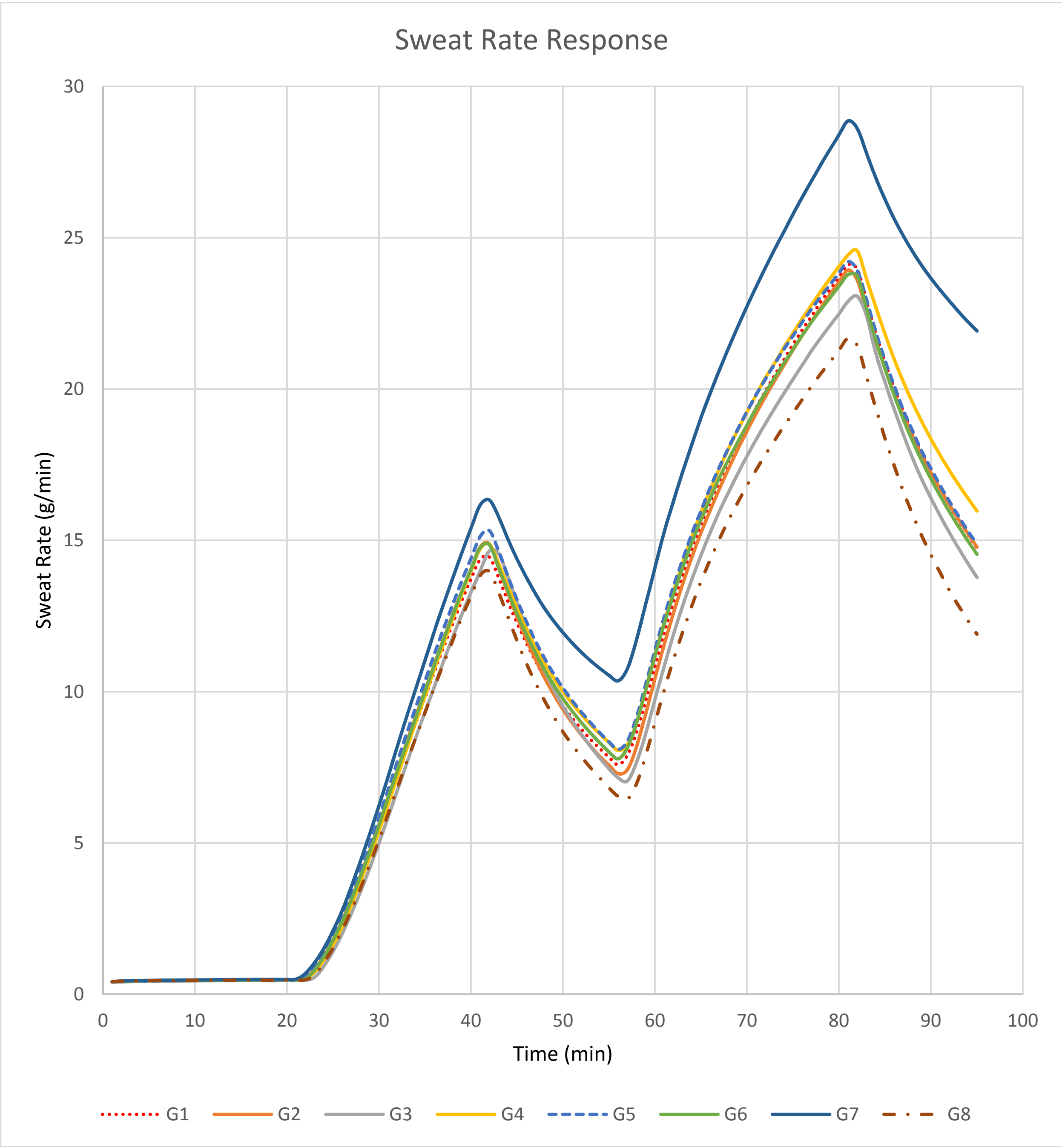
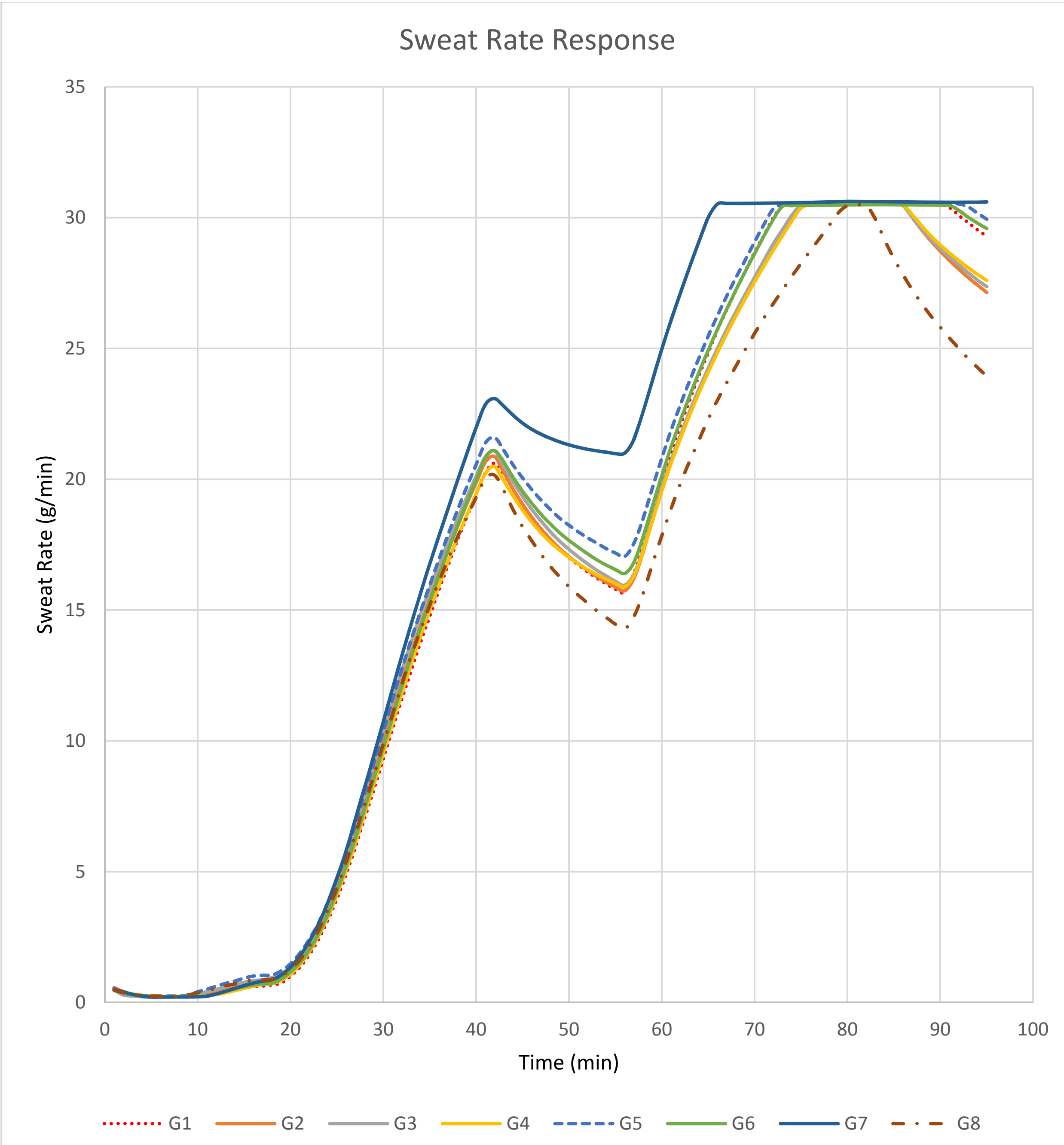
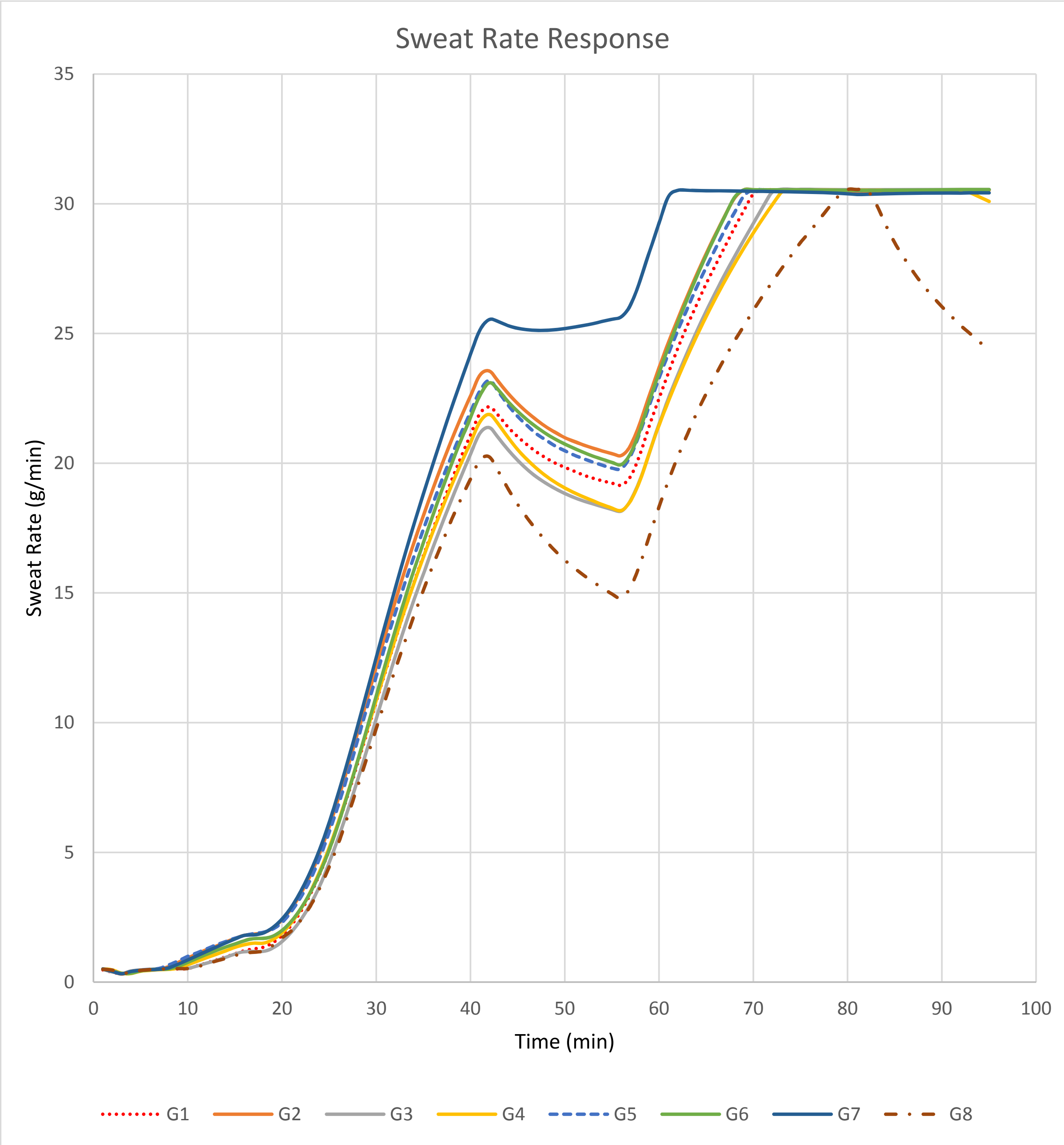


Figure 11. Predicted Sweat Rate Response (35°C 40%RH Test Condition)*




*The horizontal portion of the curve indicates that the maximum sweating amount has been reached. This value equates to approximately 30.5 g/min

Figure 12. Predicted Sweat Rate Response (40°C 20%RH Test Condition)*




*The horizontal portion of the curve indicates that the maximum sweating amount has been reached. This value equates to approximately 30.5 g/min

## Caveat

These data, obtained under controlled laboratory conditions, predict the human response to particular test garment, protocol and specific environmental conditions. One test per garment type and environmental condition of this test protocol were performed. There is some level of inherent variability associated with sweating manikin testing, so all results must be considered in this context. To establish statistical confidence in the findings, more replicate tests should be considered.

These results should not be used to appraise the safety benefits or risks of the materials, products, or assemblies in extreme use conditions. The relationships between laboratory tests and field performance are not simple, and many things must be considered when making practical translations. Clothing comfort and heat stress performance are determined by many factors including the gear worn, activity level, and the environmental conditions of use. These results do not address the full range of these issues. It is not our intention to recommend, exclude, or predict the suitability of any commercial product for a particular end use.

# Phase I

Comparing Human Data from W.L. Gore Testing to Manikin Data

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# Purpose

- To demonstrate how the physiological manikin data compares to human data
  - Acquired three sets of gear from the Gore testing project
    - X, Y, Z
    - Report released for the June 2016 NFPA 1971 meeting in Colorado Springs
  - Tested the manikin in the same manner as the human study
  - Provide a side by side comparison

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# Procedure

- Dressed manikin in socks, underwear, and T-shirt
- Donned one of the fire suits (x, y or z), helmet, gloves, and tennis shoes
- Taped up bottom of legs
- Placed manikin in a wheel chair
  - Not part of human study

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# Procedure

| Time Duration (min) | Subject Position | Description |
|---|---|---|
| 0-15 | Seated | Seated rest |
| 15-40 | Treadmill | 3.3 mph, 1% incline |
| 40-55 | Seated | Seated rest, drink water |
| 55-80 | Treadmill | 2.2 mph, 1% incline |
| 80-95 | Seated | Seated rest, drink water |

- Manikin
  - 1 Met
  - 4.5 Met, 47 DSPM
  - 1 Met,
  - 2.7 Met, 30 DSPM
  - 1 Met

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# Reminder

- DON'T expect an exact replication of the human data.
  - The manikin is not a human!
  - It uses a predictive physiological model based on the average population!
    - Not firefighters
    - Not 10 subjects
  - Model assumes an 180 lbs. average male
    - 10 subjects were an average of 198 lbs.
- Look for trends and outcomes not absolute numbers.
- Does the results mimic the ranking found in the human study?

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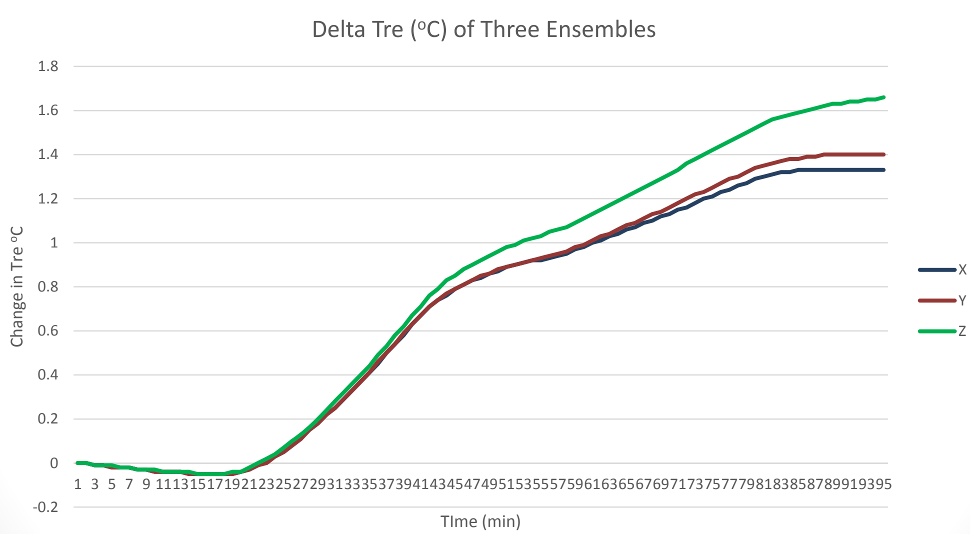
# Change in Rectal Temperature



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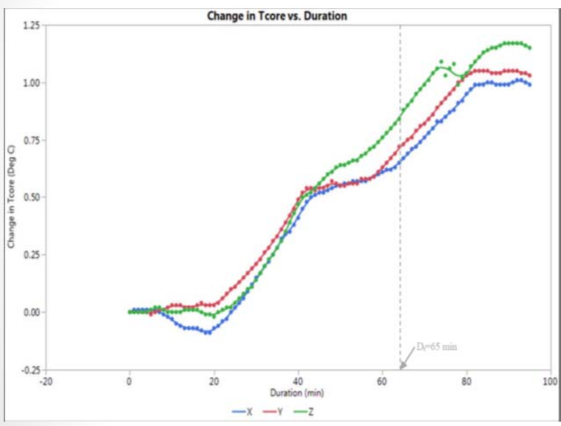


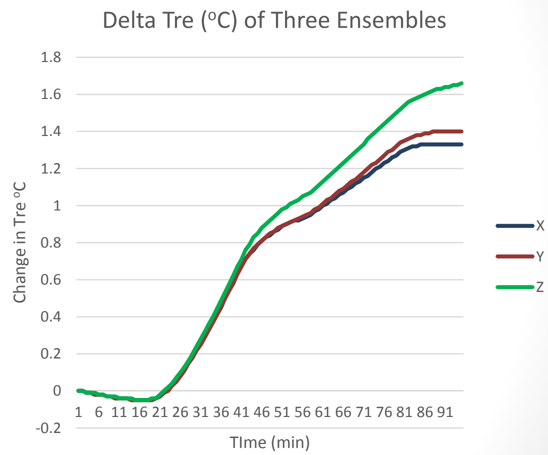


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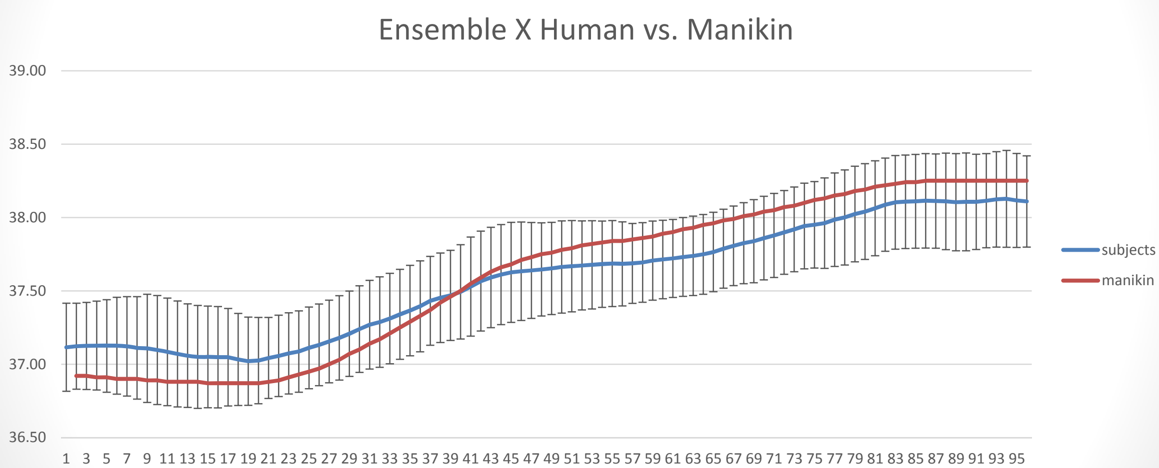

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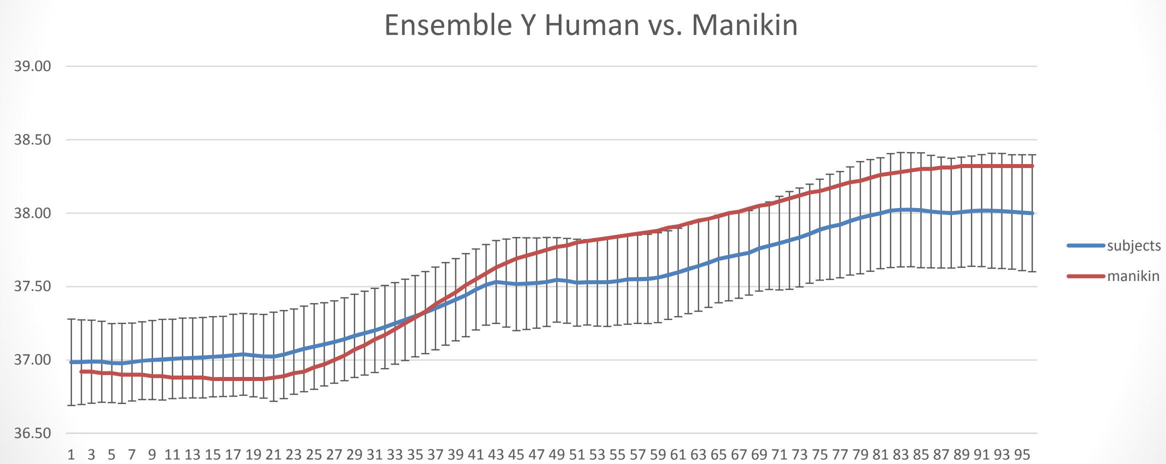


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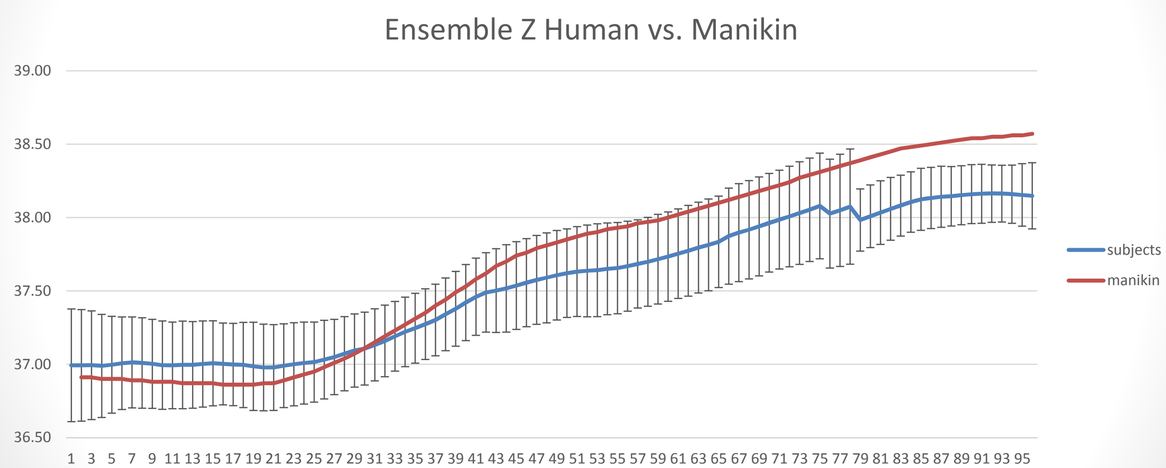

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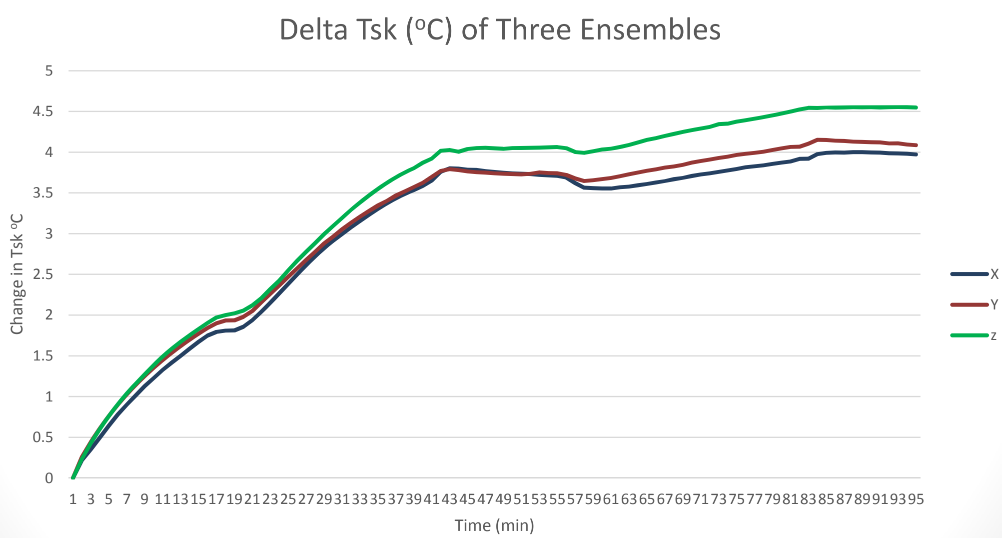


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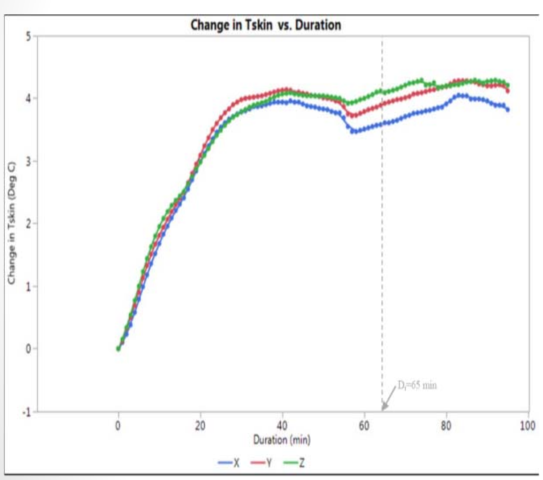


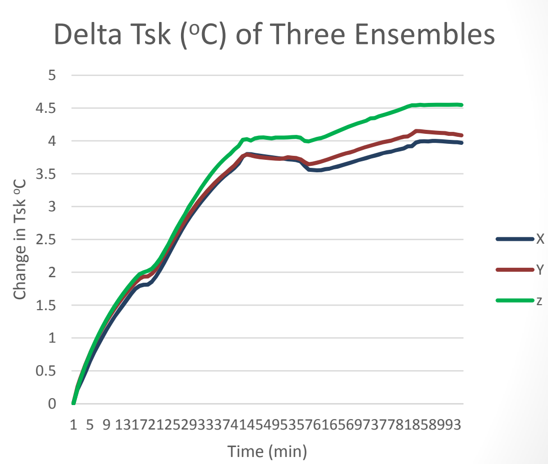

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# Sweat Loss

- Human Data
  - X 1.019 Kg
  - Y 1.055 Kg
  - Z* 1.093 Kg
- Manikin Data
  - X 1.455 Kg
  - Y 1.507 Kg
  - Z 1.709 Kg

*Loss should have been greater but 4 subjects were pulled early limiting the amount of loss

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# Outcomes

- Overall the trends were similar to the human study
- Absolute numbers were higher but within reason of human data
  - Firefighters are used to these conditions?
  - Firefighters were slightly heavier than model?
  - Manikin couldn't drink water?

## Appendix B: Protective Clothing Specifications and Composite Layer Description

### PROTECTIVE CLOTHING SPECIFICATIONS

**SCOPE:** The purpose of the clothing is to provide protection during structural fire fighting operations where there is a threat of fire or when certain physical hazards are likely to be encountered, such as during non-fire-related rescue operations, emergency medical operations, and victim extrication.
**COMPOSITE PERFORMANCE:** The garment composite, consisting of the outer shell, moisture barrier and thermal liner, shall be provided by customer. (Identification of the layers are provided at the end of this document)
**OUTER SHELL MATERIAL:** The garment outer shell material shall be as specified by customer.
**MOISTURE BARRIER MATERIAL:** The garment moisture barrier material shall be as specified by customer.
**THERMAL LINER MATERIAL:** The garment thermal liner material shall be as specified by customer.
**REFLECTIVE TRIM:** All trim shall be sewn with four rows lockstitch 301, minimum six stitches/inch for most secure trim attachment.
Trim shall be 3" Scotchlite™ Triple Trim (lime/yellow).
Coat trim shall be NFPA Pattern: One 3" strip shall be set full circumference at the bottom hem; one 3" strip shall be set around each sleeve within 2" above the cuff; one 3" strip shall be set full circumference at the chest.

Pant trim shall be one 3" strip set full circumference around the bottom of the cuff 3" from the bottom cuff.

**OPTIONAL LETTERING:** No lettering to be provided

**SIZES:** Garment sizes will be provided to fit the dimensions of the NSCU mannequin utilized for testing.

**OPTIONS:** No pockets, tabs, or other attachments no shall be added to the garments unless specified herin.

## COAT

**COAT CONSTRUCTION:** The coat shell shall be a 3-panel construction in all layers with an inverted pleat on each side where front and back body panel pieces meet. Each pleat shall begin at the back of each shoulder and shall extend vertically down the side of the coat. A combination moisture barrier/thermal liner shall include a corresponding 1" inward dynamic fold approximately 1.5" from each sleeve seam at the shoulder. This fold shall provide for coat expansion when extending arms forward and shall interface with the inverted pleats of the outer shell to maximize mobility and function of the outer shell and thermal liner. The coat shell and moisture barrier/thermal liner shall be oversized to assure proper chest fit and insure maximum mobility without restriction of the arms and shoulders. Bi-swing construction shall provide better fit, longer wear and greater comfort. When measured at the center of the back from the collar seam to the hem bottom, the coat shall measure 32" in length. Sleeves shall be of full length and of shoulder insert, 2-panel type design.

**MOISTURE BARRIER/THERMAL LINER CONSTRUCTION:** Design shall be compatible with the outer shell so that the liner does not buckle, pull, or otherwise restrict body motion. The left and right fronts of the moisture barrier/thermal liner shall be attached to the facings at the front closure of the outer shell. The moisture barrier/thermal liner shall be secured to the outer shell collar such that when donning the coat an arm may not be accidentally caught between the outer shell and its inner linings.

The moisture barrier shall be completely sewn to the thermal liner at its perimeter with the breathable membrane oriented inward toward the thermal liner and away from the outer shell. All moisture barrier seams shall be sealed. The moisture barrier/thermal liner shall finish no more than 1" from the cuffs and 3" from the hem.

**MOISTURE BARRIER/THERMAL LINER ATTACHMENT:** The moisture barrier/thermal liner shall be completely detachable from the outer shell for ease of cleaning by the use of hook and loop, zippers, and snaps. There shall be a thermoplastic zipper down each front facing, hook and loop along the neck to interface with collar as well as hook and loop and one snap at each sleeve end.

**COAT LINER INSPECTION SYSTEM:** There shall be a 10" opening located on the coat liner system at the center left front of the liner. This opening will provide the ability to completely invert the coat liner to properly view the integrity of the entire liner system. There shall be one piece 1" x 9" Loop sewn to the back side of the liner system with a piece of 1" x 9" Hook sewn to the inside of the outer shell to ensure proper alignment when installing the liner system into the outer shell. This Liner Inspection System is completely hidden when the liner is properly installed into the outer shell.

**COLLAR:** The 3" split collar shall consist of two piece construction shaped for comfort. The collar shall be configured such that when the collar is raised it shall remain standing while providing continuous thermal and moisture protection around the neck and face. To ensure this protection, the two layers of outer shell collar shall be fully lined with a layer of moisture barrier. The shell collar shall provide proper interface with the liner to insure no moisture penetration through the collar seam to the inside of coat. The shell collar shall have two pieces ¾" hook along top edge for liner attachment.

The liner collar shall be a layer of self material and a layer of moisture barrier. The design shall be compatible with the outer shell so that the liner does not buckle, pull, or otherwise restrict body motion. The left and right fronts of the liner collar shall be attached to the facings at the front closure of the outer shell. The neck of the liner collar shall be secured to the neck of the outer shell collar such that when donning the coat an arm may not be accidentally caught between the outer shell and its inner linings. A 4" wide moisture barrier material and 1.5" self-material extension shall be sewn the full length of the neck with two pieces of ¾" loop for attachment to shell collar. The self material extension shall overlap the shell collar to reduce exposure of the hook and loop. Collar closure shall be provided by Hook and loop 1.5" x 4", with hook portion sewn on right side of collar, and loop portion sewn on left, set horizontal. The collar shall be attached to the liner facing using 1" hook. Collar shall be of such design so as not to interfere with SCBA face masks, or helmet.

**THERMAL REINFORCED YOKE**: A layer of thermal liner (Total weight +/- 6.0-6.8 oz./sq. yd depending on moisture barrier) shall be positioned between the moisture barrier and thermal liner for extra thermal protection in a high heat and compression area of the coat. It shall be sewn to the inside of the upper back portion of the thermal liner across the upper back from the back shoulder and collar seams 7" down, over the tops of shoulders and down the front approximately 4" ending at the armhole.

**SHOULDER CAPS:** A four inch wide area at the top of the shoulders extending six inches from the collar seam shall be capped with self-material (Outer shell)

**BELLOWS UNDERARMS:** Bellows underarm construction shall be used in all layers of the coat-outer shell/moisture barrier/thermal liner-ensuring maximum upper body freedom of movement including complete arm mobility when reaching up and/or forward. Bellows construction shall extend to all inner layers of the coat making it possible for the fit and freedom of movement, derived from the outer shell bellows construction, to be passed through the inner layers to the wearer's body.

The outer shell/moisture barrier/thermal liner bellows shoulder construction shall consist of an underarm and shoulder bellows of elongated football shape not less than 8" wide by not less than 15" long sewn into each of the coats fabric layers by two-needle construction. The bellows in each layer shall begin at a point corresponding to the front of the armpit, wrap around under the arm and shoulder joint, and terminate at the rear top of the shoulder.

**ELBOW:** The sleeve shall have an insert throughout all layers that shall provide a natural bend in the sleeve. This insert shall be set in the back of each sleeve and shall be a shortened football shape, 6" wide in the middle and 3" wide at the seams. No additional elbow reinforcement shall be provided.

**SLEEVE WELL:** A combination thermal liner and moisture barrier leader shall be sewn no more than 1" back from the combination liner sleeve end to form a sleeve well. One male snap and one .75"wide strip of Loop shall be sewn full circumference to the end of the thermal liner/moisture barrier leader to help secure the combination liner to the outer shell. This sleeve well shall reduce water and hazardous materials from entering the sleeve when arms are in a raised position.

The combination liner sleeve ends shall be inserted into the outer shell sleeve ends by means of lining up the male snaps then attaching the Loop fastener of the combination liner sleeve end with the female snap and Hook fastener of the outer shell cuff. This method of combination liner attachment shall reduce any gaps from occurring between the combination liner and sleeve well during a full range of motion. The combination liner shall extend to within 1" of the sleeve end.

**WRISTLETS:** An internal wristlet shall consist of a 2-ply NOMEX®/Spandex knit not less than 4". Wristlets shall be double stitched and bound to the moisture barrier/thermal liner providing extended thermal and slash protection.

**CUFFS:** The cuff of the sleeve shall be reinforced with a binding of self-material (outer shell) not less than 3" in total width for abrasion resistance and thermal protection. At least 2" of the cuff reinforcement shall extend down the interior of the outer shell sleeve with a .75" wide strip of Hook sewn full circumference to the topside of the cuff reinforcement. For added safety, one female snap fastener shall be set in the hook fastener to assist in attaching outer shell to moisture barrier/thermal liner.

**THERMAL FRONT PANEL CONSTRUCTION:** There shall be continuous thermal and moisture protection around the entire torso including the storm flap. To ensure this protection, as well as reduce potential for wicking moisture to inside of liner, both right and left inside front facings of the coat outer shell shall incorporate outer shell fabric and moisture barrier, extending from collar to hem

**COAT FRONT CLOSURE DESIGN:** The complete outer shell coat front closure design shall consist of a FRONT CLOSURE SYSTEM completely protected by an OUTSIDE STORM FLAP which shall have its own, independent STORM FLAP CLOSURE SYSTEM.

**STORM FLAP:** A storm flap measuring not less than 3" wide, nor less than 22" in length shall be set on the outside of the right side of the coat opening for maximum thermal protection and clear drainage. The inner lining of the storm flap shall be moisture barrier sandwiched between two layers of outer shell fabric.

**Zipper/Hook and Loop Front Storm Flap Closure:** The front closure shall consist of a #9 thermoplastic zipper such that fast closure and exit is possible yet the coat remains securely closed while working. The storm flap closure shall consist of 1.5" wide Hook and loop attachments with Hook fastener sewn with four rows lockstitch on the left front of the coat, and corresponding Loop fastener sewn with four rows lockstitch on the inner side of the outer storm flap. The hook and loop closure shall extend the full length of the outer storm flap eliminating all exposed frontal hardware.

## PANT

**PANT CONSTRUCTION:** The multi-piece, low-rise waist pant is designed to be worn with any 32” or longer coat.

**MOISTURE BARRIER/THERMAL LINER CONSTRUCTION:** Design shall be compatible with the outer shell so that the liner does not buckle, pull, or otherwise restrict body motion. The waist of the moisture barrier/thermal liner shall be secured to the waist of the outer shell such that when donning the pant a leg may not be accidentally caught between the outer shell and its inner linings along the waist and between the legs of the pant.

The moisture barrier shall be completely sewn to the thermal liner at its perimeter with the breathable membrane oriented inward toward the thermal liner and away from the outer shell. The moisture barrier/thermal liner shall finish no more than 3" from the cuffs.

**MOISTURE BARRIER/THERMAL LINER ATTACHMENT**: The moisture barrier/thermal liner shall be completely detachable from the outer shell for ease of cleaning by using snaps. Eight evenly spaced snaps shall secure the liner to the inner waistband; two snaps shall be set in leather leg tabs at each leg end.

**PANT LINER INSPECTION SYSTEM:** There shall be an opening located on the pant liner system to the right side of the waist separating the thermal barrier and moisture barrier, approximately 10" in length. This opening will provide the ability to completely invert the pant liner to properly view the integrity of the entire liner system. There shall be a piece of 1" x 3" Loop sewn to the moisture barrier 3" over from beginning of opening and a corresponding piece of 1" x 3" Hook sewn to the inside of the outer shell to ensure proper alignment when installing the liner system into the outer shell. This Liner Inspection System is completely hidden when the liner is properly installed into the outer shell.

**STORM FLY/CLOSURE:** The outer shell shall have an overlapping fly front running the full length of the fly on the left side. The flap shall not be less than 2.5" wide at the waistband. The bottom of the fly shall be reinforced with one 42-stitch bartack. The storm fly shall be outer shell material, lined with a 3.5” strip of moisture barrier material to reduce wicking.

**Hook and loop storm fly/zipper pants closure:** Pant closure shall be provided by #9 thermoplastic zipper. The storm fly shall be held closed along its length by means of a hook and loop fastener closure 1.5" minimum width sewn with four rows lockstitch, along the leading edge for a distance of not less than 6" from the bottom of the fly closure to the waist area for proper alignment and secure closure. Additionally, one snap shall be positioned at the inside top of the fly.

**WAISTBAND:** The waist of the pants shall be reinforced on the inside with two-ply of outer shell material not less than 1.5" in width. The pant waist shall be turned under to provide double material strength with the independent waistband, which shall then be double stitched to the outer shell. Eight suspender buttons shall be appropriately spaced around the waistband to accommodate the use of suspenders.

**EXTERNAL TAKE-UPS:** One adjustment device shall be affixed to the outside on each side of the pant. Each take-up strap shall be comprised of two sub-component straps. The front strap shall be 1" wide x 5" in length, folded in half to form a loop, and shall be affixed to the side of the pant by means of two bar tacks spaced 2" apart. The loop shall face toward the back and hold a nickel plated 1" metal loop. The back strap shall be 1" wide x 9" in length of double layered outer shell material and hook and loop fastener. The rear 4.5" shall be sewn and triple bartacked to the shell. The front section of the strap shall remain loose and be aligned so that it is threaded through the metal loop. It shall have a piece of 1" x 3" hook fastener attached to the loose strap end to engage the corresponding 1" x 4.5" loop fastener at end of strap to allow for adjustment.

**RADIAL INSEAM BAND**: The pant inseam shall incorporate a comfort/mobility design in all layers. The banded pant insert shall run continuously from the top of the mobile knee of one leg, through the crotch, to the top of the mobile knee of the opposite leg. This design eliminates crotch seams therefore eliminating crotch seam failure. This design also provides a more comfortable fit and increased mobility while decreasing bunching of materials.

**KNEE:** The knee shall incorporate a comfort/mobility design in all layers. This design shall allow for a natural bending motion of the knee. The knee shall be self-material (outer shell) and measure 9" across the bottom, not less than 7" on the sides and gradually increase to 12" at the center point at the apex. The apex of the knee shall allow for not less than a 1.5" bellows at the center. The radial seam shall provide a gusset that the knee can fall into when crawling, climbing, bending, kneeling, etc. The bottom of the mobile knee shall be placed not less than 10" from the cuff to fall anatomically correct.

**KNEE PADDING:** In addition to reinforcement, knees shall be padded using one layer of thermal liner material and one layer of moisture barrier. The reinforcement material shall be oriented between the outer shell and knee insert reinforcement.

**CUFFS:** The cuff area of the pant shall be reinforced with a binding of self-material (outer shell) not less than 2" in total width for greater strength, abrasion resistance, and thermal protection. In addition a 3” x 3 ½” piece of reinforcement material shall be sewn on the inseam area of the pant leg above the pant cuff and below the pant trim, in order to provide extra abrasion protection. The material used on the kick shield shall match the material used on the pants cuffs.

## Composite Layer Identification

| **G1** | |
|---|---|
| Outer shell | 7.5 oz/yd$^2$ plain weave ( 93% Nomex®/5% Kevlar®/2% anti-static blend spun yarn) |
| Moisture Barrier | 4.6 oz/yd$^2$ (bicomponent ePTFE laminated to a Nomex® spunlace) |
| Thermal liner | 7.1 oz/yd$^2$ (2 layers of Basofil®-/Aramid blend spunlaced quilted to Nomex® spun yarn, calendared plain weave fabric) |

| **G2** | |
|---|---|
| Outer shell | 7.5 oz/yd$^2$ plain weave ( 93% Nomex®/5% Kevlar®/2% anti-static blend spun yarn) |
| Moisture Barrier | 5.2 oz/yd$^2$ (bicomponent ePTFE laminated to Nomex® spunlace) |
| Thermal liner | 7.2 oz/yd$^2$ (single layer of aramid fiber needle punched fabric quilted to 100% Nomex® spun fiber, plain weave fabric) |

| **G3** | |
|---|---|
| Outer shell | 7.5 oz/yd$^2$ plain weave ( 93% Nomex®/5% Kevlar®/2% anti-static blend spun yarn) |
| Moisture Barrier | 5.2 oz/yd$^2$ (bicomponent ePTFE laminated to 80% Nomex IIIA / 20% PBI woven pajama-check) |
| Thermal liner | 7.2 oz/yd$^2$ (two layers of Nomex® spunlaced fabrics [1.5 and 2.3 oz/yd$^2$] quilted to 100% Nomex® spun fiber, plain weave fabric) |

| **G4** | |
|---|---|
| Outer shell | 7.0 oz/yd$^2$ twill weave (70**%** PBI/Kevlar® spun yarns and 30% Kevlar filament yarns) |
| Moisture barrier & Thermal liner system | 98% NOMEX®/2% anti-static spun yarn woven fabric, plain weave, laminated to an ePTFE film |
| | Kevlar®/Nomex® blend patterned nonwoven spunlace with scrim, laminated to an ePTFE film |
| | 60% Kevlar® filament yarn / 40% Nomex®/ Lenzing®FR blend spun yarn, twill weave, coupled with an ePTFE film |

| **G5** | |
|---|---|
| Outer shell | 7.0 oz/yd$^2$ twill weave (70**%** PBI/Kevlar® spun yarns and 30% Kevlar filament yarns) |
| Moisture Barrier | 4.7 oz/yd$^2$ (bicomponent ePTFE laminated to 100% Nomex® woven pajama-check) |
| Thermal liner | 6.8 oz/yd$^2$ (two layers of 80% Aramid 20% PBI apertured spunlaced fabrics [1.4 and 1.8 oz/yd$^2$] quilted to 60% Kevlar®, 26% Nomex®, 14% Lenzing FR, twill weave fabric) |

| G6 | |
|---|---|
| Outer shell | 7.0 oz/yd$^2$ twill weave (70**%** PBI/Kevlar® spun yarns and 30% Kevlar filament yarns) |
| Moisture Barrier | 5.2 oz/yd$^2$ (bicomponent ePTFE laminated to 80% Nomex IIIA / 20% PBI woven pajama-check) |
| Thermal liner | 6.8 oz/yd$^2$ (two layers of 80% Aramid 20% PBI apertured spunlaced fabrics [1.4 and 1.8 oz/yd$^2$] quilted to 60% Kevlar®, 26% Nomex®, 14% Lenzing FR, twill weave fabric) |

| G7 | |
|---|---|
| Outer shell | 7.75 oz/yd$^2$ Twill with rip stop (Blend of Kevlar® and Basofil® fibers) |
| Moisture Barrier | 9 oz/yd$^2$ (Neoprene laminated to a poly cotton cloth) |
| Thermal liner | 9.25 oz/yd$^2$ (single layer of recycled Nomex quilt, quilted to Nomex® spun fiber, plain weave fabric) |

| G8 | |
|---|---|
| Outer shell | 5.3 oz/yd$^2$ ripstop ( Blend of Technora® and PBO spun yarns) |
| Moisture Barrier | 4.5oz/yd$^2$ 100% Nomex® pajama-check |
| Thermal liner | 7.6oz/yd$^{2(}$ single layer of 50% Nomex® 50% Kevlar® needle-punched quilted to a 68% Kevlar®, 26% FR Viscose, 11% Polyamide ring spun fabric) |

## Appendix C: Thermal Neutral Temperature Set Points

Table 4 represents the temperature set points for each individual zone that every test began at.

Table 4: Thermal Neutral Temperature Set Points

| Device Names | Temperature Set Point |
|---|---|
| Face | 32.44 |
| Head | 33.39 |
| R Up Arm Fr | 33.17 |
| R Up Arm Bk | 33.63 |
| L Up Arm Fr | 33.15 |
| L Up Arm Bk | 33.76 |
| R Forearm Fr | 33.30 |
| R Forearm Bk | 33.30 |
| L Forearm Fr | 33.30 |
| L Forearm Bk | 33.30 |
| R Hand | 33.30 |
| L Hand | 33.30 |
| Upper Chest | 33.86 |
| Shoulders | 33.86 |
| Stomach | 33.30 |
| Mid Back | 33.48 |
| Waist | 33.30 |
| Lower Back | 33.30 |
| R Up Thigh Fr | 34.22 |
| R Up Thigh Grd | 34.82 |
| R Up Thigh Bk | 34.89 |
| L Up Thigh Fr | 34.40 |
| L Up Thigh Grd | 35.22 |
| L Up Thigh Bk | 35.30 |
| R Lwr Thigh Fr | 34.20 |
| R Lwr Thigh Bk | 34.21 |
| L Lwr Thigh Fr | 34.40 |
| L Lwr Thigh Bk | 33.93 |
| R Calf Fr | 34.24 |
| R Calf Bk | 33.97 |
| L Calf Fr | 35.31 |
| L Calf Bk | 34.83 |
| R Foot | 34.12 |
| L Foot | 33.51 |