Meet “Liz” - Female Sweating Thermal Manikin

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Thermetrics

About Thermetrics

We Bring Comfort to Life

- Seattle-based manufacturer of specialty thermal instrumentation – heat/moisture transfer and human simulation
- Equipment and services to demystify the in-use performance of garments and textiles
- Thermetrics products are focused on evaluation from raw fabric through end-use application





Topic Outline

Please post questions as they arise…

- Survey - Rate your manikin mastery
- Thermal manikin background
- Why female manikins?
- Why Liz? Results of our naming contest.
- Overview of Liz
  - Morphology
  - Sensing and heating
  - Sweating system
  - Data output
- Applicable test methods
- Measurement results
- Q&A

Why Use a Thermal Manikin?

Garment
- Material selection
- Garment layers
- Fit and air gap
- Active features

Manikin Regulation
- Skin temperature
- Sweat rate

Ambient Conditions
- Local air temperature
- Air velocity
- Radiant wall temperature
- Solar intensity
- Relative humidity

Standard Measures
- Steady state heating power
- Calculation of Thermal and Evaporative Resistance (Rc, Re)

Advanced Measures
- Power differences
- Mass balance
- Human simulation

Female Representation and Influence

49.6% of world population[1]

- Career Firefighter 4.1%[2]
- Volunteer Firefighter 7.0%[2]
- Female Enlisted US Military 16%[3]
- Global women's activewear: $216 billion by 2025[4]

Women will continue to be a major driver for advances in protective and performance clothing

(1) https://ourworldindata.org/gender-ratio#what-share-of-the-population-is-male-and-female
(2) https://www.nfpa.org/-/media/Files/News-and-Research/Fire-statistics-and-reports/Emergency-responders/osFDProfileTables.pdf
(3) https://www.cfr.org/backgrounder/demographics-us-military
(4) https://www.alliedmarketresearch.com/press-release/womens-activewear-market.html

Garment Fit Impacts Safety & Performance

- Poorly fitting garments affect mobility and microclimate
- Garment performance dominated by materials and air gaps
  - Trapped air typically increases Rc, Re.
  - Increased protection from hot/cold environment
  - Reduced heat loss from skin (heat stress risk)
- Growing research base around fit and function, much more is needed

Impact on Safety and Performance

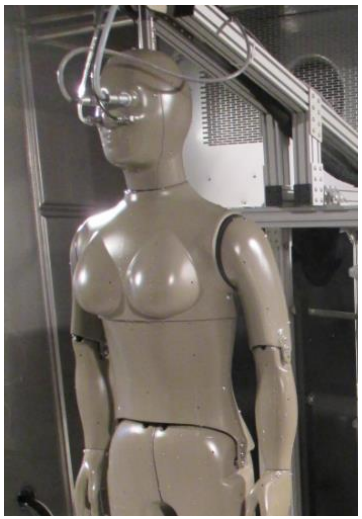
“Many of the nearly 94,000 women firefighters in the United States are forced to use gear that doesn't fit them properly, which puts them at higher risk for injury.”

NFPA JOURNAL

https://www.nfpa.org/News-and-Research/Publications-and-media/NFPA-Journal/2021/Spring-2021/POV/Perspectives

Thermetrics Female Manikins in Use

- Of >100 Thermetrics manikins in service, only 2 are female
- Newton manikin option: removable chest region (now discontinued)



Origin of the name "Liz"

- Wide range of past practices for naming Thermetrics manikins
- Our question: How to honor the rise of women in science – with a manikin?
- Crowdsourcing: First, nominations. Second, votes.

Finalist Names	Nominated but not selected
Cori: Gerty Cori, 1st woman to win Nobel Prize in physiology, 1947, for glucose metabolism discovery **Joules**: Derived energy unit, frequently used in manikin and human energy balance **Liz** : Dr. Elizabeth McCullough, world renowned manikin researcher and retired Director of KSU-IER	**Eve**: A natural choice **Hope**: Certainly needed in the midst of a global pandemic **Marie/Curie** : Groundbreaking woman scientist, first woman to win a Nobel Prize **Sakura**: Cherry blossom, representing renewal and optimism

Dr. Elizabeth McCullough

- The name Liz/Elizabeth was nominated twice
- Final voting results

Liz	54%
Joules	25%
Cori	21%

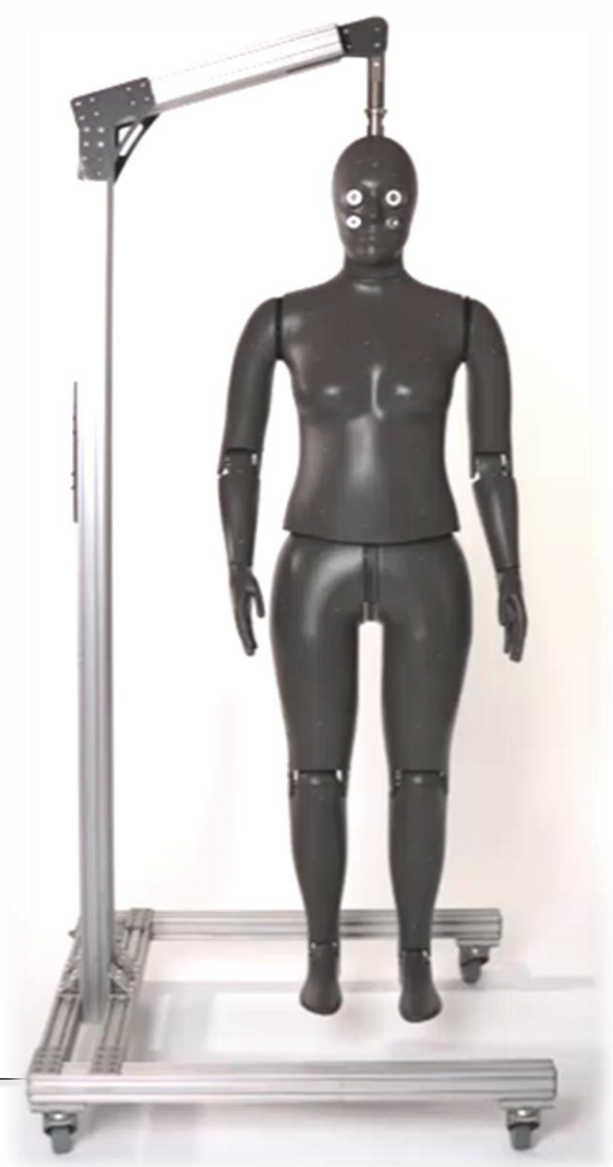
Dr. Elizabeth McCullough, a world-renowned manikin researcher and retired Director of KSU-IER. No female scientist worldwide has done more than Dr. McCullough with thermal manikins to advance testing, development, and standardization of improved protective clothing, sleeping systems, and personal protective equipment.

We are extremely proud to help continue Dr. McCullough's transformational work through the Liz thermal manikin

Meet Liz – DOB Feb 5, 2021

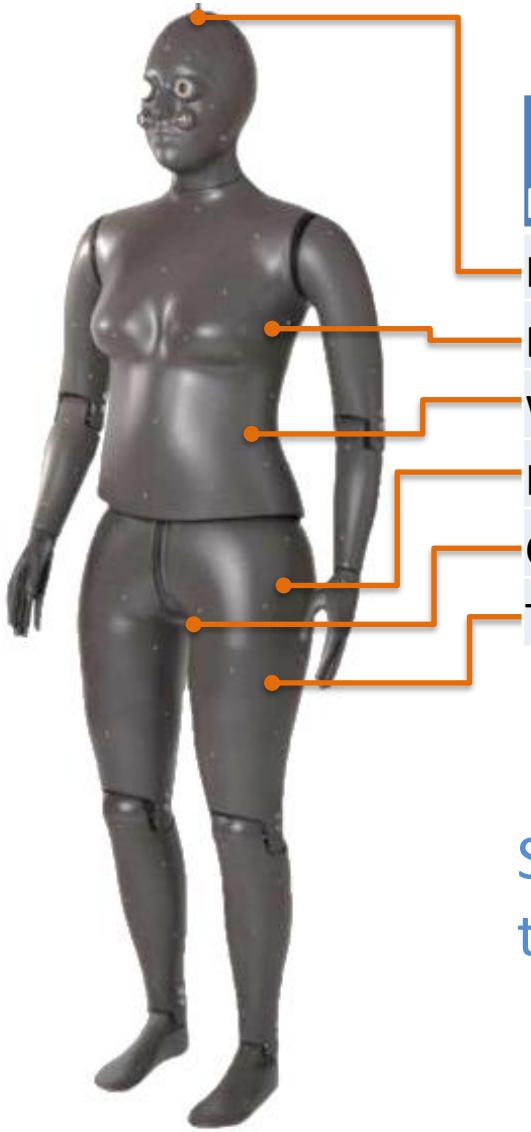
- 30-zone Female Thermal Manikin
- Carbon-epoxy shell
- Embedded heating and sensor wire elements
- Articulated joints at the shoulders, elbows, hips, knees, and ankles
- Integration with ThermDAC software
- Complies with ASTM F1291, F1720, F2370, F2371, F2732, EN 13537, EN 342, ISO 15831, ISO 23537

Parameter	Value
Temperature	+-0.1 degC
Power output	700 W/m2
Sweat delivery	0-2000ml/hr
Operational temp range	-20°C to +50°C



Liz Body Form

- Based on 3D CAD composite from actual subject scans
- Benchmarked to existing anthropometrics studies
- Adapted for joint articulation and range of motion



Measure	Dim (cm)	Dim (inches)
Height	167.4	65.9
Bust Circ	93.8	36.9
Waist Circ	76.3	30.0
Hip Circ	99.9	39.3
Crotch Ht	76.9	30.3
Thigh Circ	58.9	23.2

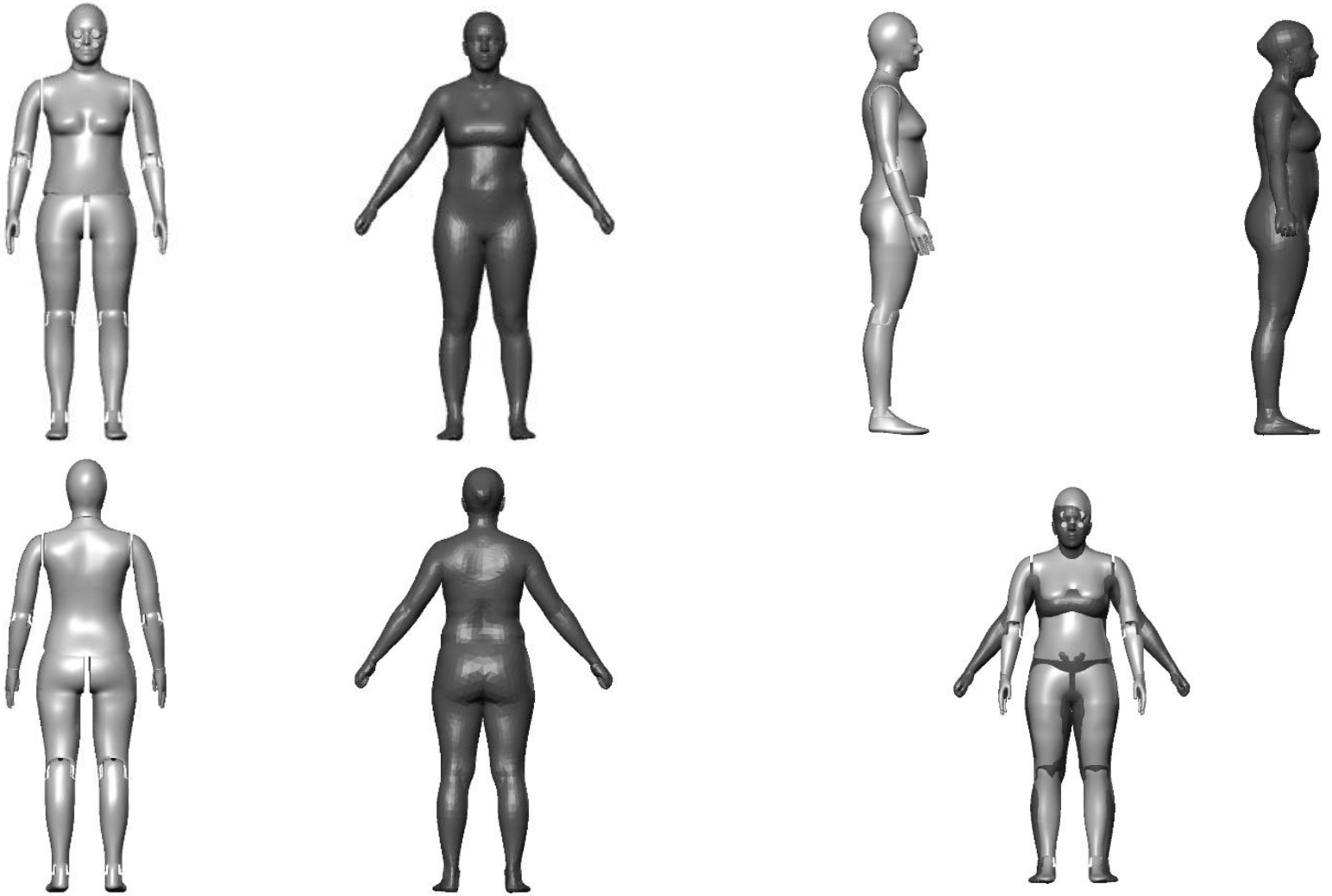
Sizing maps to US Size 10

Dimensional Benchmarking

	Liz Dim (cm)	ASTM D5585-21[1] (Size 10)	CACFOA Study[2] (50th %ile)	US Army ANSUR II[3] (50th %ile)	CDC Firefighter Study[4] (50th %ile)
Height	167.4	166.4	167.9	162.6	166.8
Bust Circ	93.8	94.6	94.4	94.0	95.5
Waist Circ	76.3	77.5	77.9	85.2	85.9
Hip Circ	99.9	100.3	102.9	101.8	104.4
Crotch Ht	76.9	77.5	76.5	78.0	74.3
Thigh Circ	58.9	57.8	59.3	61.3	61.0

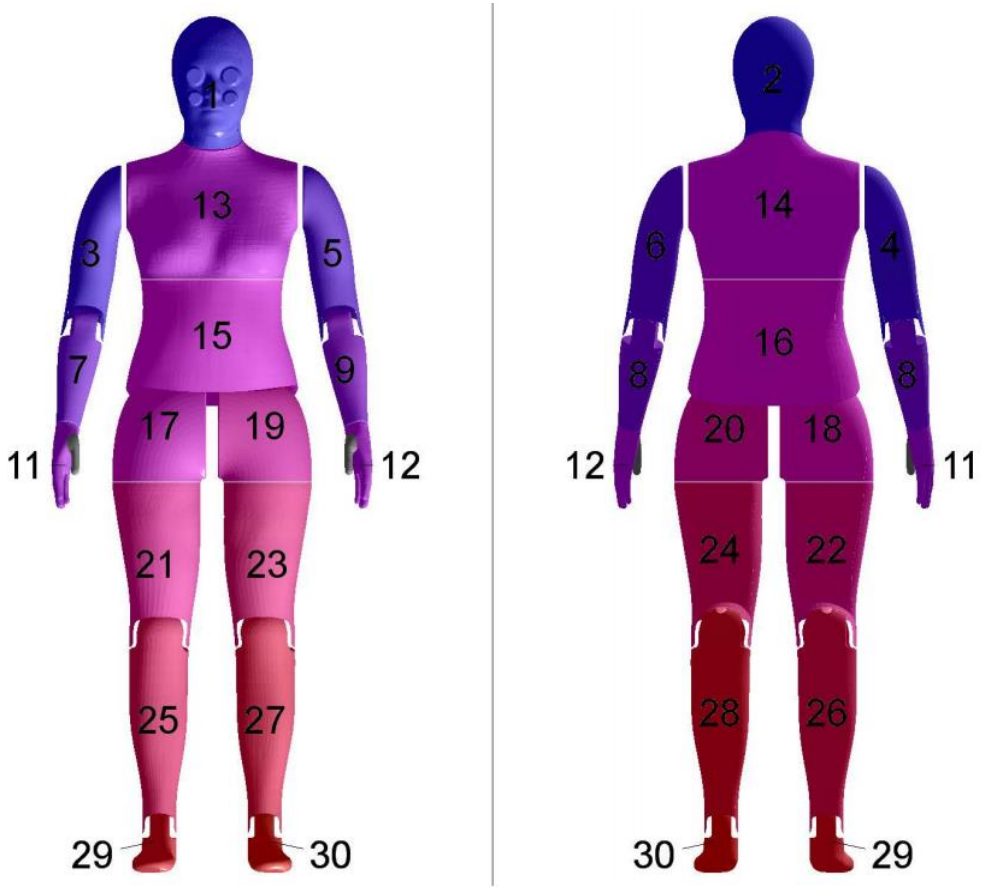
(1) https://www1.astm.org/Standards/D5585.htm
(2) https://www.humanics-es.com/FireFighterAnthropometry.pdf
(3) https://www.openlab.psu.edu/ansur2/
(4) https://www.cdc.gov/niosh/data/datasets/rd-1007-2015-0/pdfs/firefighter-anthropometry-71-measurements-508.pdf

Visual Comparison with ANSUR II Subject Scan

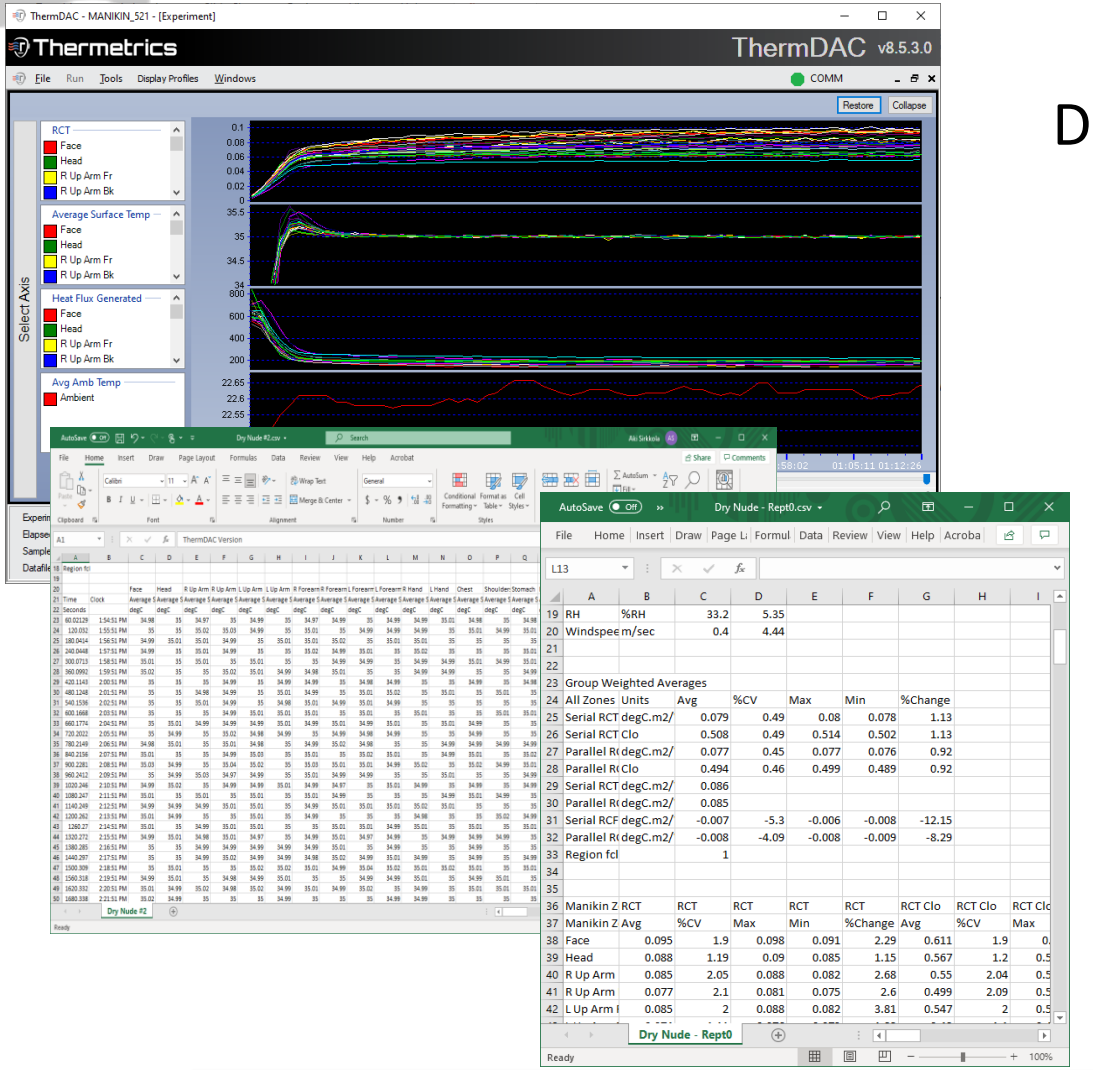


Segmentation and Control

- 30 thermal zones
- Embedded distributed heater and sensor wire at each zone
- Each zone individually controlled to Temperature/HF/sweat rate
- Individual results from each zone with automatic body averaging



Test Results / Reporting

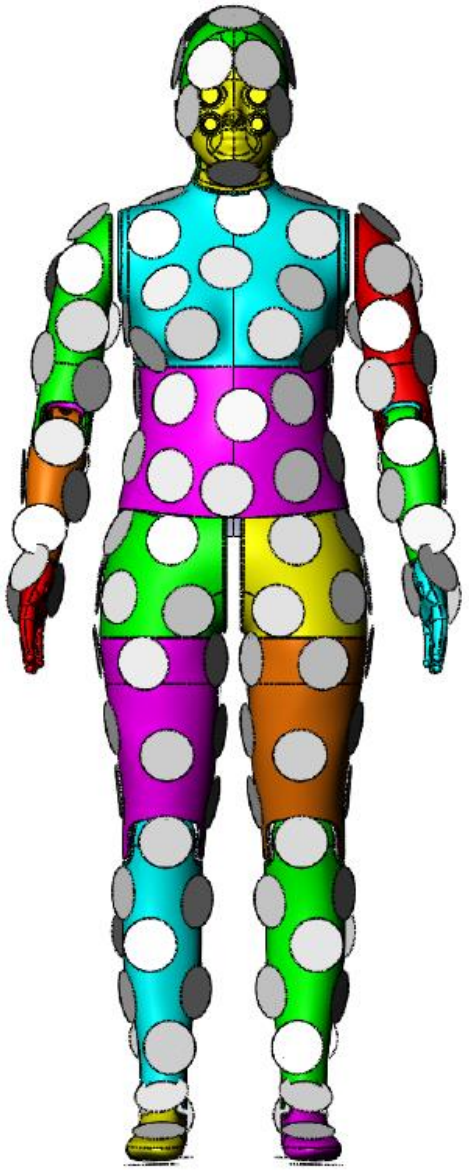


Data Outputs

- Realtime graphs in ThermDAC
- CSV Raw data file with time stamped temperatures, sensor outputs, machine parameters
- CSV summary report with just the good stuff
- File loadback functionality

Sweating System - Option

- Computer-controlled fluid delivery with removable wicking fabric skin
- Independent control for each zone
- Higher pore density than Newton
- 162 Quick-change sweat pores for easy maintenance



Additional Options

- Walking motion stand
- External breathing system with humidifier and tracer gas inlet
- ManikinPC physiological software model
- Cold capable for operation to -30° C

Test Methods – and Gaps

- Compliant vs Relevant?
- Existing manikin Test methods are gender-neutral, specify wide range of dimensions

Standards Body	Manikin Height (cm)	Surface Area (m2)
ASTM	160 to 180	1.5 to 2.1
ISO	155 to 185	1.4 to 2.0
EN	150 TO 190	1.5 TO 2.1

- But do they meet the needs of consumers and producers?
- Typical language (ISO 15831-2004, Reviewed 2018):

  "The manikin's body proportions should correspond to those required for standard sizes of garments, because deviations in fit will affect the results."

- Discussion underway on ASTM F23.60 about calibration garments and broader impacts of gender in standards

Measurement Results

Shirt: Bulwark SMU3NV
Pants: Bulwark FP45NV
Cotton undergarments

ASTM F1291 - Thermal Insulation (dry manikin)

Male Newton (n=6)		Female Liz (n=1)		
Zone	R_{cl}	Zone	R_{cl}	R_{cl} % Delta
Body Average	0.122	Body Average	0.113	-7.4%
Arms	0.197	Arms	0.172	-12.7%
Upper Torso	0.138	Upper Torso	0.254	84.1%
Lower Torso	0.288	Lower Torso	0.249	-13.5%
Hips	0.453	Hips	0.294	-35.1%
Upper Legs	0.140	Upper Legs	0.096	-31.4%
Lower Legs	0.131	Lower Legs	0.095	-27.5%

ASTM F2370 - Evaporative Resistance (sweating manikin)

Male Newton (n=6)		Female Liz (n=1)		
Zone	R_{ecl}	Zone	R_{ecl}	R_{ecl} % Delta
Body Average	17.40	Body Average	15.72	-9.7%
Arms	25.50	Arms	21.78	-14.6%
Upper Torso	14.41	Upper Torso	27.91	93.7%
Lower Torso	42.57	Lower Torso	34.51	-18.9%
Hips	57.52	Hips	30.59	-46.8%
Upper Legs	21.64	Upper Legs	11.31	-47.7%
Lower Legs	22.52	Lower Legs	16.45	-27.0%

Summary and Next Steps

- Females are awesome, empowered, and not the same as males
- Fit and physiology are key differences not well-represented in current research, measurement, standards
- All manikin test methods should be evaluated for gender relevance
- Liz and Thermetrics are ready to support your research, equipment needs, future rentals

Additional References

- International Association of Women in Fire & Emergency Service https://www.womeninfire.org/
- Effect of structural turnout suit fit on female versus male firefighter range of motion, McQuerry (2020) https://www.researchgate.net/publication/336375868_Effect_of_structural_turnout_suit_fit_on_female_versus_male_firefighter_range_of_motion
- Anthropomorphic Fit Evaluation of Structural Firefighters' Protective Pants: A Gender Comparison Study, Langseth-Schmidt (2004) https://mountainscholar.org/bitstream/handle/10217/88567/LangsethSchmidt_colostate_0053N_12684.pdf?sequence=1&isAllowed=y
- Analysis of Air Gap Volume in Structural Firefighter Turnout Suit Constructions in Relation to Heat Loss, McQuerry et al. (2018) https://www.researchgate.net/publication/318724730_Analysis_of_Air_Gap_Volume_in_Structural_Firefighter_Turnout_Suit_Constructions_in_Relation_to_Heat_Loss
- Thermal Manikin Evaluation of Gender Sweat Differences While Wearing a Ballistic Vest, Domina el al. (2016), https://www.researchgate.net/publication/283828531_Thermal_Manikin_Evaluation_of_Gender_Sweat_Differences_While_Wearing_a_Ballistic_Vest
- Investigation of the Contribution of Garment Design to Thermal Protection. Part 1: Characterizing Air Gaps using Three-dimensional Body Scanning for Women's Protective Clothing, Mah et al. (2010), https://www.researchgate.net/publication/249785974_Investigation_of_the_Contribution_of_Garment_Design_to_Thermal_Protection_Part_1_Characterizing_Air_Gaps_using_Three-dimensional_Body_Scanning_for_Women's_Protective_Clothing
- Firefighters' protective jackets: Fit to female form and its effects on attributes relevant to thermal comfort (2018), https://www.tandfonline.com/doi/full/10.1080/15459624.2018.1506587

Save the Date for Webinar #2

- Thursday, July 15th at 10 a.m. PST
- Topic Outline
  - Using Liz thermal manikin
    - Testing overview
    - ThermDAC Software
    - Results and data analysis
  - Female thermoregulation (Mark Hepokoski, ThermoAnalytics)
  - Using Liz and ManikinPC for human simulation

Thank You!

Please take our very brief post-webinar survey