META-COOLING TEXTILE

Performance Team

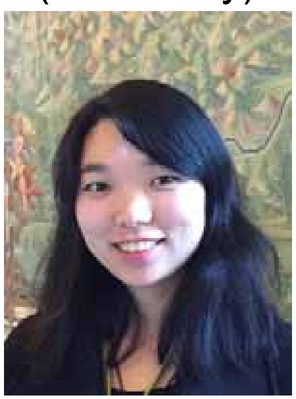
YuHuang Wang (PI)
(Chemistry)

Min Ouyang
(Physics)

Bao Yang
(Mech. Eng.)

Bing Hu
(MSE)

YuHuang Wang (PI)- nanotechnology & materials chemistry
Min Ouyang- meta physics and modeling
Bao Yang – thermal management
Liangbing Hu- textile processing



Min Li
Postdoctoral lead

Shulong Li
Senior Scientist and Innovation Lead,
Milliken & Company

Edmir Silva
Corporate Product Development
Unifi Manufacturing, Inc.

Duration of Award: May 1, 2015-April 30, 2018

META COOLING TEXTILE WITH SYNERGETIC INFRARED RADIATION AND AIR CONVECTION FOR BIDIRECTIONAL THERMOREGULATION

Technology Summary

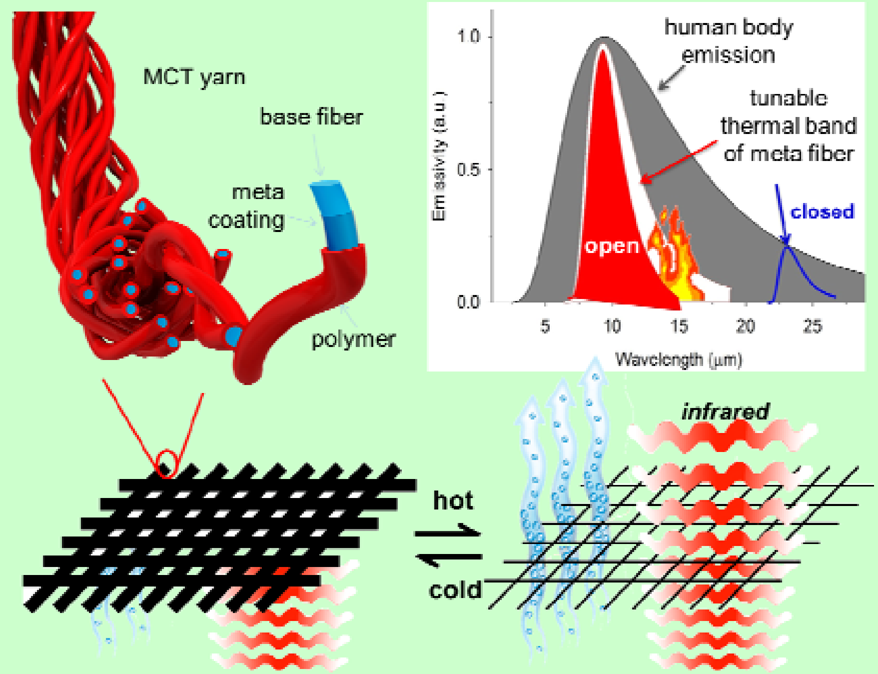
- *Active infrared properties control in clothing, for the first time, through innovative meta-fiber technology.*
- *Self-powered autonomous regulation of clothing for thermal comfort.*
- *Maximize the efficiency of localized cooling/warming through synergetic actions of all 4 major mechanisms.*

Value Proposition

- *A unique new function for clothing to help penetrate the >$600B global industry of apparel.*
- *Potential to reduce energy cost of buildings that can total 2% of all energy used in the United States.*

Uniqueness Claim

Metric	State of the Art (air conditioned clothes)	Proposed
Added Thermoregulation Capacity	*N/A*	*41 W*
Self-regulation	*No*	*Yes*
Power Consumption	*2.5 -5 W*	*0*
Weight Increase	*> 10%*	*2.5%*
Cost Increase per T-shirt	*~ $100*	*$0.88 - 3.42*



- MCT integrates nanostructures with ideal thermal band and responsive inter-coupling to effectively manage thermal comfort by synergetic control over infrared radiation and the other heat exchange channels.
- When hot, the yarns shrinks, the nanostructures interact to maximize emission, the body cools effectively. When cold, the reverse effects occur.

Efficient LTMS with bidirectional thermoregulation at a fraction of cost.

Patents pending

MCT vs. State-of-the-Art Wearable LTMS

- Cooling vests (including evaporative cooling)
- Sweat wicking (e.g. Nike Sphere React and AeroReact)
- Air-conditioned jackets
- Disadvantages (air-conditioned jackets specifically):
  - Bulky (require 2 fans, control box, cable, and 4 AA batteries every 5 hours)
  - Costly ($140 or more per system)
  - One direction regulation/lack of infrared control

Nike AeroReact (Oct. 2015)

Kuchofuku Air-Conditioned Cooling Coat

MCT harnesses infrared radiation synergistically with the other channels

- Principle:
  - *Adjustable infrared properties* with synergetic control over evaporation and air convection
- Strategy:
  - Meta coupling effect
  - Moisture/thermally responsive fibers
- Method:
  - Experimental and computational
- Targets:
  - Add 23 W (summer) + 18 W (Winter) thermoregulation capacity

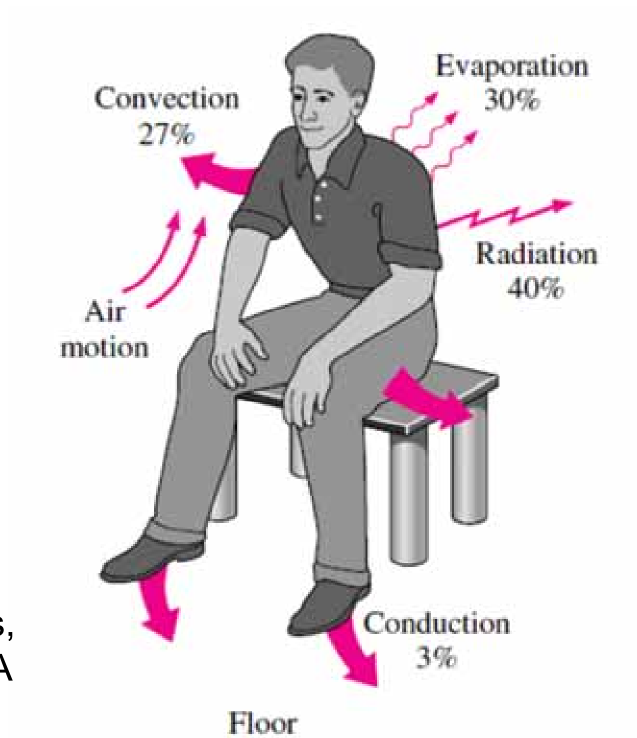


Figure credit:
Dr. Ping Liu, DELTA: Delivering Efficient Local Thermal Amenities, Presented at Delivering Efficient Local Thermal Amenities. DELTA Kickoff Meeting, May 21-22, 2015, Portland, OR

Key Parameters of Performance and Where We Are

Baseline Clothing

Temperature Setpoint	Total Thermal Resistance (m^2 F/W)
Lower, 70 ºF	0.40
Upper, 75 ºF	0.31

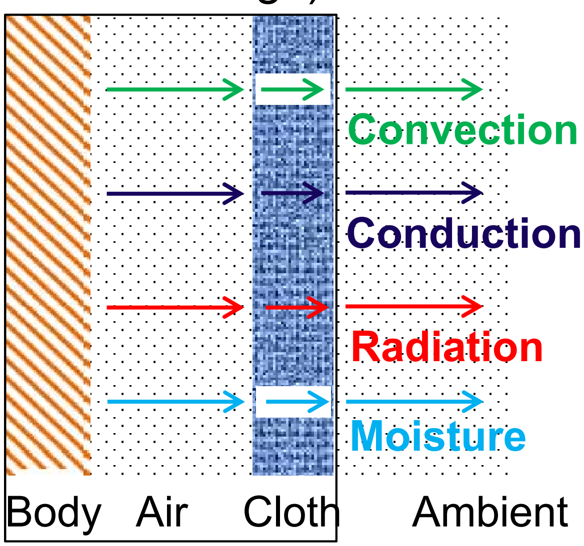
Updated MCT metrics based on 5^{th} generation thermal modeling (vs. proposed)

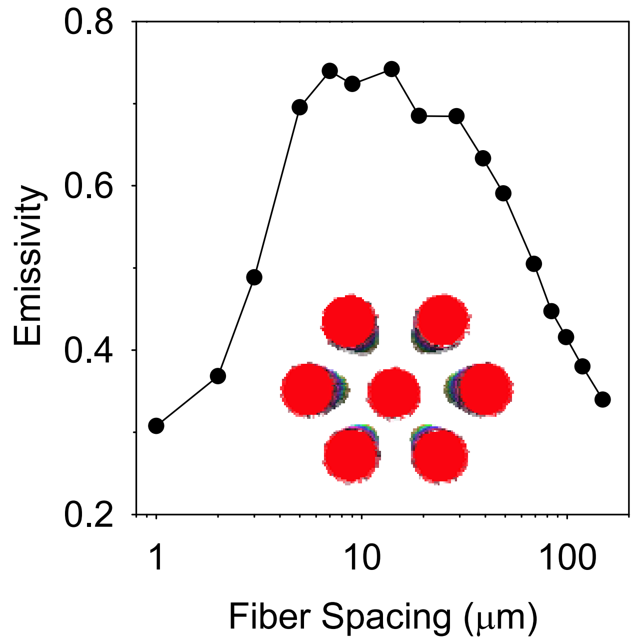
Temperature Setpoint	Radiation (m^2 F/W)	Conduction (m^2 F/W)	Convection (m^2 F/W)	Moisture (m^2 F/W)	Total Thermal Resistance (m^2 F/W)
Expanded Lower, 66 ºF	1.86 (1.98)	0.02 (0.1)	0.16 (0.61)	3.25 (3.52)	0.46
Expanded Upper, 79 ºF	0.77 (0.65)	0.013 (0.032)	0.21 (0.41)	2.18 (2.36)	0.24
Added Thermoregulation Capacity (W)	15.7 (20.9)	22.1 (17.3)		3.12 (2.8)	

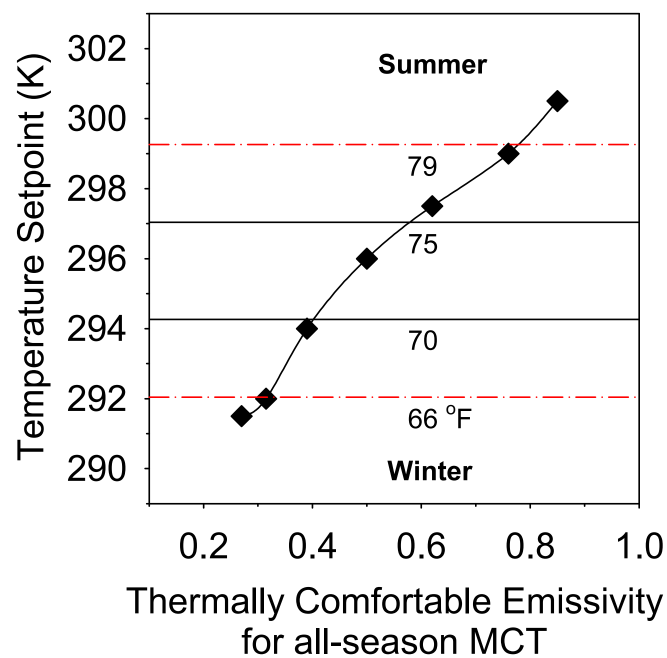
Performance target		Q7	Q8	Q9	Q10	Q11	Q12
T equivalent	Meta Fiber	0.25 ºC	±0.5 ºC	±1 ºC	±1.5 ºC	±2 ºC	
	MCT				±0.5 ºC	±1 ºC	±2 ºC

Key Interim Learning and Results
Theoretical Model

- Finite-difference time-domain modeling of infrared optical properties.
- 4-layer thermal model of clothing built with Ansys Fluent.
- *Coupled* convection, conduction, radiation, and evaporation (in office settings).





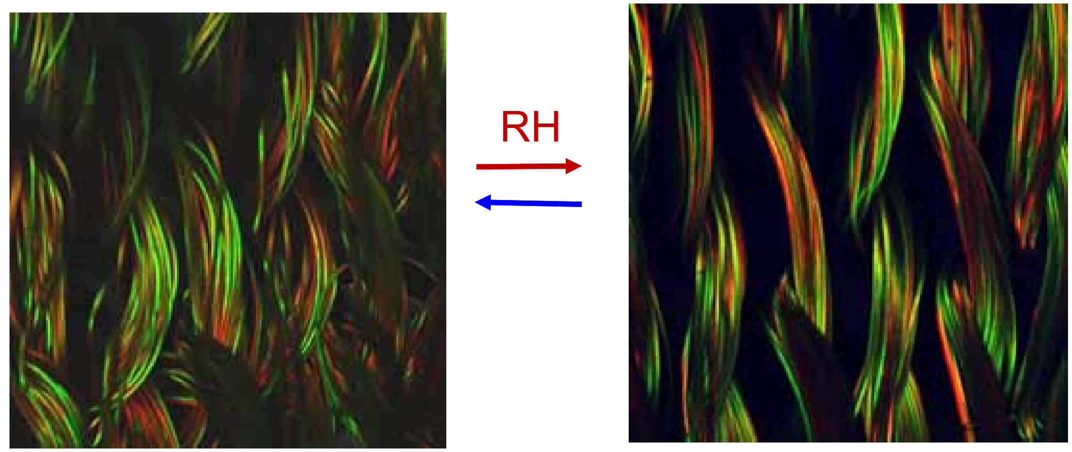


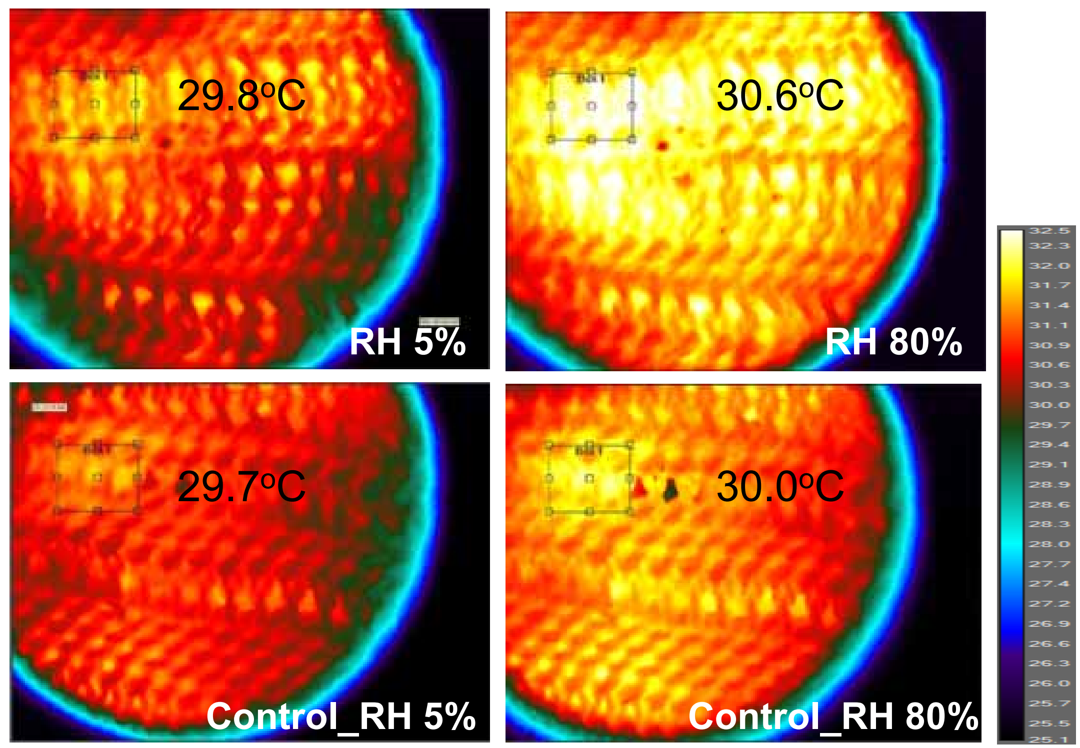
- FDTD optical modeling predicts tunable emissivity in the infrared by adjusting the fiber spacing.
- Numeric thermal model predicts that a setpoint expansion of ± 4 °F can be achieved by proposed MCT technology.

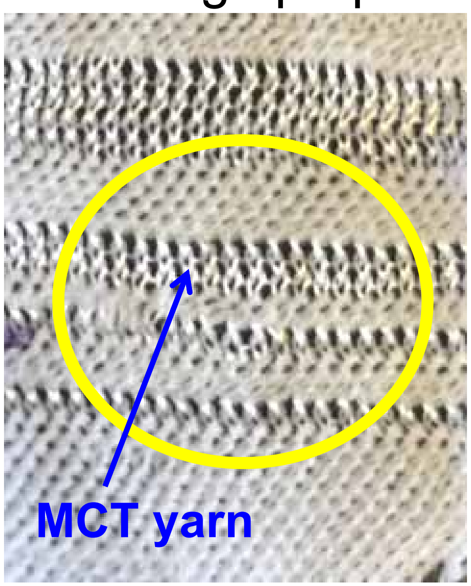
Key Interim Learning and Results

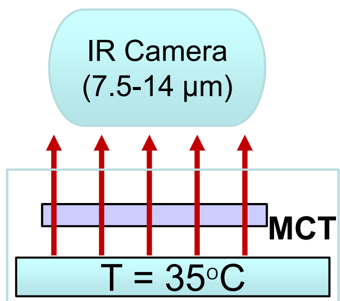
Dynamic Infrared Response

- 1st MCT prototype demonstrates autonomously tunable infrared emissivity by more than 10%, adding ~1.2°F to thermoregulation capacity.
- Our data suggest, for the first time, that dynamic response in the infrared can be achieved through proposed MCT.



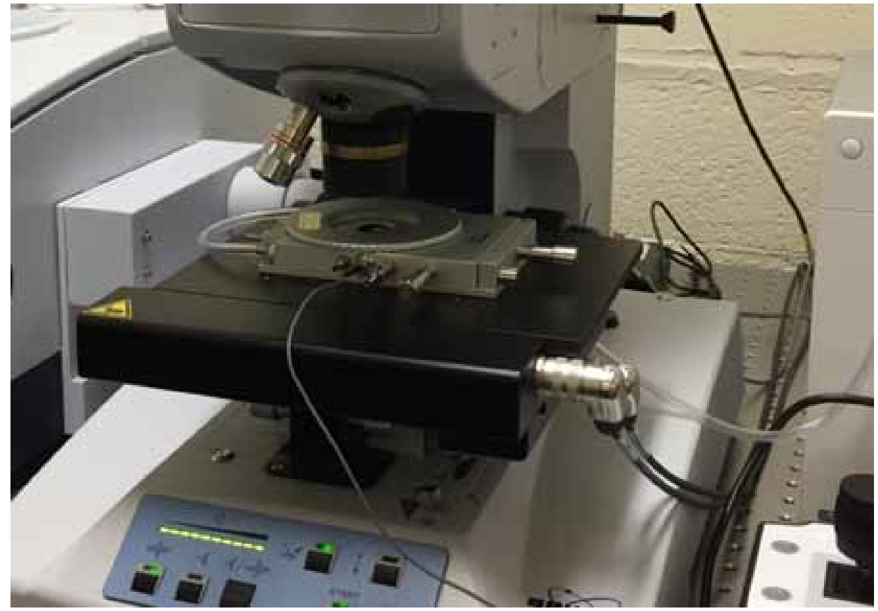






Key Interim Learning and Results

Infrared Measurement System



- Spectrally resolved, quantitative IR measurements of dynamic systems?
- Environmental chamber integrated FTIR system
- Transmittance + Reflection + Emission
  - MCT detector covering 1-22 µm or 1-16 µm with microscope
- Humidity and temperature controls
  - Temperature control with 0.1 ^{o}C accuracy
  - Humidity control over 5-95% with a stability of +/- 0.5%
- Newly installed motorized stage for mapping

Summary

- Theoretical optical and thermal modeling predicts a setpoint expansion of ± 4 ^{o}F can be achieved by proposed MCT technology.
- A proof-of-concept demonstration of proposed MCT has been established through the design of meta fibers and knitted fabric.
- First prototypical MCT fabric already shows dynamically tunable infrared properties by more than 10%, adding ~1.2 ^{o}F to the thermoregulation capacity.

The Road Ahead

- Our project is well on track to deliver a MCT prototype with robust dynamic control over infrared radiation and other main heat exchange channels to achieve bi-directional thermoregulation.
- Next steps are focused on performance optimization through design-fabrication-characterization loops.

How the DELTA Community Can Help?

1. **Markets/Applications/Technology**
   - Finding first applications and first markets
2. **Experts to connect**
   - Knitting and yarn processing of (fragile) samples on smaller scales.
3. **Suggestions/opportunities for MCT**
   - Collaborations/Partnerships on product development/MCT technology applications

Questions? Comments? Suggestions? Please contact

YuHuang Wang: yhw@umd.edu