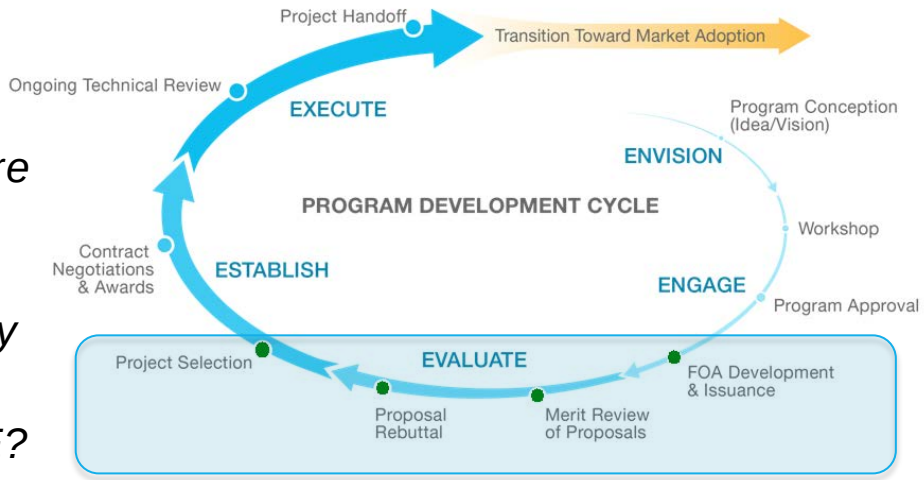
BREAKOUT Instructions Sheet:

<u>Day 1</u>: Why Now?

- Attendees pitch their quads
- 7 minutes total including:
  Intro, pitch, and Q&A.
- Audience follows up with questions by considering ARPA-E like criteria:
  - ***Impact***: *If project targets & metrics are achieved, will it matter?*
  - ***Transform***: *Is it a significant departure from the SOA? Are the risk factors fully outlined?*
  - ***Bridge***: *Is it uniquely suited for ARPA-E?*
  - ***Team***: *What set of capabilities and/or experiences are needed for execution?*



NOTE: Not all speakers will be detailing a specific approach but may focus on value-add content for the breakout.

Breakout Group #3

First Name	Last Name	Company/Organization
Jonathan	**Burbaum**	**ARPA-E Moderator**
Russel	**Ross**	**Booz Allen Hamilton**
Vince	Baranauskas	NanoSonic
Gang	Chen	MIT
Bruce	Conger	Jacobs Engineering
Jim	Freihaut	PSU - DOE Energy Innovation Hub
Mike	Gibson	MIT
Meagan	Gleason	Under Armour
Warren	Jasper	NCSU
Hilary	Lackritz	SRI International
Pete	Lynn	Otherlab
QiBing	Pei	UCLA
Behnam	Pourdeyhimi	North Carolina State University
Michelle	Povinelli	University of Southern California

Hybrid Personal Comfort Garments for Indoor Use

Vince Baranauskas

Adaptive thermal garments realized from NanoSonic's technologies may provide **0.02 clo/°F** changes to provide occupant comfort & allow building neutral bands to be expanded to: **64 - 80 °F, saving 1% of the national energy consumption.**

Problem Statement

- The majority of the nation's yearly energy expenditures are spent on the thermal control of commercial and residential buildings and yet **~20% of occupants can not achieve thermal comfort**.
- Adaptive personal garments may **provide thermal comfort to building occupants** who are not currently achieving thermal comfort while *allowing expansion of the neutral band*.

Approach

- **Transparency** of garment designs with respect to dexterity would be the main emphasis in an R & D effort.
- Garments will leverage the following technologies: **Nanostructured Thermally Responsive Foams** & **Patterned Conductive Textiles.**

Potential Solutions

- **Thermally responsive foams** with insulation values that change with temperature.
- **Patterned conductive textiles** whose active Joule heating changes as function of voltage.
- A **combination** of passive & active technologies.
- **Thermally reflective clothing** – reducing the heat loss of the wearer.
- Garments based on **phase change material (PCM)** embedded capsules.

Scientific & Technical Challenges

- Technical challenges: designing an array functional garments that can maintain transparency to the wearer *and* achieve style.
- Scientific challenges: material processing, production scale-up.

Personal Climate Control System (PCCS)

Dr. Gang Chen
gchen2@mit.edu
617-253-3523

Personal climate control system which can remove 100W of body heat or generate 100W of heat (reducing building HVAC requirements by 20%)

Problem Statement

- Heating/cooling makes up large percentage of total energy consumption in buildings (48% residential, 30% commercial)
- By reducing the temperature difference between external environment and building interior, a ~30% reduction in energy usage per 10°C reduction can be achieved

Approach

- Currently, building HVAC systems handle 100% of heating/cooling loads – resulting in energy waste
- Our approach is to reduce building's HVAC load and establish a "temperature band" of ± 10°C for these systems to operate
- Personal energy-efficient climate-control systems (wearable on each user) will enable building occupant to maintain a comfortable local temperature

Potential Solutions

- We will develop a personal climate-control system which provides localized heating/cooling device
  - Integration of a two-tier cooling system using (1) a passive phase change-based system which provides baseline cooling, and (2) active thermoelectric elements to provide additional user control when passive capabilities are exceeded
  - Integration of a distributed electric-based heating system

Scientific & Technical Challenges

- Developing specialized synthetic fibers required to implement passive phase change-based cooling system in a comfortable garment-like device
- Coupling passive phase-change cooling and active electric heating systems into single coherent device
- Developing power supply/charging stations
- Sizing of both cooling and heating systems to meet targeted goals

Evaluation and Down-Select of Multiple Personal Thermal Control Solutions at the Johnson Space Center

Bruce Conger
Jacobs Contract
NASA Johnson Space Center
bruce.conger@jacobs.com

By performing detailed analysis and testing of proposed solutions, building heating and cooling costs savings will be maximized.

Problem Statement

- Of the potential solutions listed below as well as those proposed by others, which are the best in reducing building heating and cooling costs?
  - Many solutions are proposed which can be assessed at JSC, the center of excellence for human spaceflight with significant experience in evaluating human thermal comfort.
  - Since the best of these solutions will be selected as a result of the planned screening approach, the building energy savings will be maximized.

Approach

The screening approach to evaluate individual potential solutions as well as combinations of solutions:

- Perform preliminary down-select of proposed solutions using detailed human comfort evaluations with human thermal models currently being used for spacesuit and spaceship environmental and thermal control assessments.
- Perform testing using the JSC facilities to further evaluate the down-selected solutions. Facilities include: human rated test chambers (air and wall temperature control) and human manikin testing (heated body and breathing simulation).
- Evaluate test results for effectiveness, useful life, ease of use, economy, and robustness. This final assessment will result in the selection of the best solution(s) that will maximize building energy savings.

Potential Solutions

- Flexible and highly insulating aerogel integrated into clothing
- Phase Change Material (PCM) integrated into clothing (example: OUTLAST® technology)
- Thermally conductive clothing using carbon nano-fibers/electrically conductive (for potential sensors and data transfer) textiles
- Variable emissivity textiles for clothing and other applications
- Water permeable clothing for enhanced evaporative cooling
- Thermoelectric technology integrated into garment
- Ventilated clothing including forced ventilation options
- Localized “cocoon” thermal control solutions which could include any of the above technologies
  - Seats
  - Curtains
  - Panels built into desk
  - Cubical panels
  - Individual/localized ventilation and thermostat control

Scientific & Technical Challenges

- Usage life of proposed solutions under repeated wearing and laundering conditions
- Robustness of technologies (e.g. is aerogel sufficiently resistant to damage?)
- Water compatibility (e.g. user may need to separate thermoelectric layer before laundering)
- Power consumption and practicality – for powered solutions, how much power is needed and how is it delivered?
- Economics of solutions – life cycle and up front costs must be factored into building heating and cooling cost assessment.
- Ease of use - users must be able to easily accept and adopt technology implementation

Smart local heating & cooling for custom thermal comfort

Michael A Gibson
mike@wristifyme.com
774-270-2347

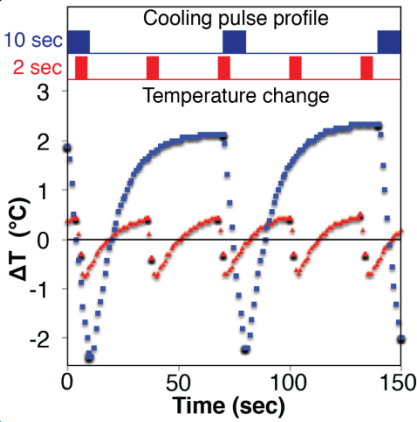
Heating and cooling of buildings uses 17% of total US energy consumption.
90 kWh/month/home can be saved per degree C change in household temperature

Problem Statement

- Excessive amounts of energy are used heating and cooling *buildings*, when it is often the *people* we wish to keep comfortable.
- ~100 kWh/month can be saved in a typical home if the home is heated or cooled by just 1 ^{0}C less. Local heating and cooling to alter human behavior to achieve such savings presents a large opportunity for energy savings and increasing quality of life in communal spaces.

Approach

- Humans are more sensitive to rates of temperature change than absolute temperatures.
- Wearable device delivers pulsed thermal waveforms to the body via Peltier cooling & resistive heating to maximize psychological effect per unit energy input.



Potential Solutions

	Fan	Pumped water	Phase change	Evap. water	Peltier cooling
ΔT tunable	✓	✓	×	×	✓
ΔT rapid, reversible	×	×	×	×	✓
Quiet	×	×	✓	✓	✓
Moving parts	×	×	✓	×	✓
Lifetime	?	?	×	×	?

Scientific & Technical Challenges

- Demonstrated technical proof-of-concept: users prefer pulsed heating and cooling in all surveys.
- Large Challenge: optimization in a multivariate design space of an objective function which is difficult to empirically measure: thermal comfort.

Variable	Benefit	Cost
Battery Size	Device Life	Weight, Bulk
Pulse Time	Temperature Amplitude	Pulse Frequency
TE Area	More heat transfer	Bulk, device life

Insert an active title for your concept

Dr. Warren J. Jasper
wjasper@ncsu.edu

Extend thermal comfort zone +/- 4 degrees F using active feedback control

Problem Statement

- Passive measures alone will not transport enough heat needed for comfort.
- If the thermal comfort zone can be extended by 4 degrees F using micro-climate control, then the total US electrical energy consumption can be reduced by 1%.

Approach

- Use a series of SOC devices (Raspberry Pi, Arduino Lily Pad), sensors and actuators to develop a closed loop microclimate control environment.
- New small, low power and inexpensive microcontrollers will allow for the development of wearable wireless devices to transmit temp/humidity to off-board fans/heaters to heat/cool occupant in a micro-controlled environment.

Potential Solutions

- Potential candidate technologies:
  - Wireless Power
  - Arduino/Raspberry Pi SOC microcontrollers
  - High efficiency fans
  - Embedded systems and sensors
  - Solid state cooling devices (Peltier Cooling)

Scientific & Technical Challenges

- Integration and retrofitting existing workspace with micro-climate controllers.
- Wireless power transmission (health and safety concerns, efficiency)
- Modeling and testing articulated system

Nano-enabled materials for personal thermal management

Hilary Lackritz
SRI International
hilary.lackritz@sri.com
(650) 859-5968

SRI International (SRI) will develop passive/active multi-layered garments that combine highly conductive engineered nanomaterials with controlled layer thermal contact for optimized individual comfort

Problem Statement

- Personal thermal comfort can be adjusted using nanomaterial-embedded clothing in both active and passive modes to control the thermal comfort of occupants who can control their own environment
- If success is attained, costs of heating buildings will decrease significantly, and individual personal comfort will increase, yielding improvements in workforce efficiency.
- By developing classes of material/textile solutions that can enable personal control, advances in comfort, compliance, even personal health and safety can be achieved.

Approach

- SRI will engineer new classes of materials/textiles to enable thermal comfort and tailorability. A first approach may be creating fabric by *targeted* addition of new nanomaterials and layers. We will determine the *minimum* cost of alteration needed to achieve a modest level of temperature control while preserving wearability
- SRI has several technologies that can be applied to personal thermal management systems. SRI's "Biomimetic Exosuit" technologies developed under the DARPA Warrior Web program are also applicable. Expertise within SRI also includes materials synthesis, materials modeling, simulation, and measurement.

Potential Solutions

- Prioritized list of potential candidate technologies include:

  Material Classes including:
  - Nanomaterials
  - Specialty polymers
  - Organic small molecules

  Flexible electronics active systems including
  - Embedded sensors
  - External sensors

Scientific & Technical Challenges

- The largest risk factor for this program is determining how people experience heat/cold individually. SRI proposes to perform the human sensation analysis required to understand how an individual experiences temperature, so that materials and technologies developed by any ARPA-E contractor can be accurately tested with quantitative metrics.
- Other risks include cost/garment and wearability and durability

Inflatable Engines, Heat Pumps, and Heat Exchangers

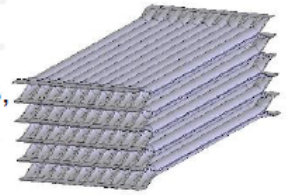
Peter Lynn
pete@otherlab.com

Directly quantifiable improvement in exergy efficiency of thermal management.
More qualitative increase in human comfort for a given gross energy input.

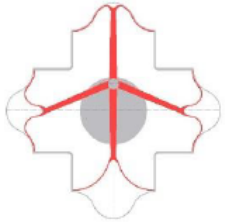
Problem Statement

- Extending the scope slightly, how can we use modern advances in light-weight high-strength and low-cost textiles and polymer based membranes to decentralize energy systems, dramatically increase energy efficiency, and extend our energy capabilities?
- A large proportion of energy used is expended on heating and cooling. These energy loads can potentially be greatly decreased by more efficient and much more directly targeted thermal management systems.

Approach



- Develop construction methods for manufacture of inflatable heat exchangers, characterize prototypes.
- Model, prototype, and test inflatable heat pumps. Down select thermodynamic cycle, whether Stirling, vapor compression, or isothermal counter flow.
- Model, prototype, and test wearable micro inflatable engine capable of driving a heat pump. Down select organic Rankine, Stirling, Diesel or Otto cycle.



Potential Solutions

- Water cooled/heated thermal underwear.
- Evacuated compliant multi-layer insulation.
- Wearable solid state thermo-tunneling heat pump.
- Active insulation.
- Compliant conformal thermal batteries and gas tanks.
- Combined inflatable heat engine heat pumps.
- Wearable compliant and conformal heat exchangers.
- Wearable compliant and conformal batteries.
- Solid state micro-gap thermal photovoltaic generators.

Scientific & Technical Challenges

- Bonding effectiveness of inflatable heat exchanger films and automated assembly of complex geometries.
- Working fluid containment of micro heat pump and achievement of high coefficient of performance.
- Longevity of the engine “diaphragm” with elevated temperatures and high cycle life.
- Noise

All material contained on this slide is Public Releasable content.

Smart Textile for Actuated Personal Thermal Management

Qibing Pei
UCLA
310-8254215
qpei@seas.ucla.edu

We propose the development of smart textile capable of controlled porosity and convection for personal thermal management

Problem Statement

- Personal thermal comfort has been managed by a combination of clothing (passive approach) and heating/air-conditioning (active).
- Passive approach only provide partial solutions.
- HVAC consumes excessive energy.
- Active PTM improve personal comfort, but requires a smart material capable of large-strain actuation, of low cost, non-toxic, and highly flexible.

Approach

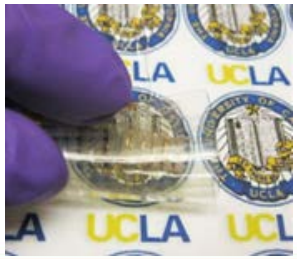
- Smart textile comprising micoractuators for electrically controlled breathability and local convection.
- Stretchable battery or wireless power supply
- Local feedback and control

Potential Solutions

- Smart clothing consists of localized sensing and actuation for local thermal management.
- Microactuator design in a simple and compact architecture
- Embedded stretchable sensors
- Design for comfort and aesthetic appearance.

Scientific & Technical Challenges

- Compact power supply by rechargeable battery or wireless by induction
- Integration of multiple components in a compact and flexible package.



Nonwoven Based Engineered Structures

Behnam Pourdeyhimi
Associate Dean, NC State College of Textiles
bpourdey@ncsu.edu

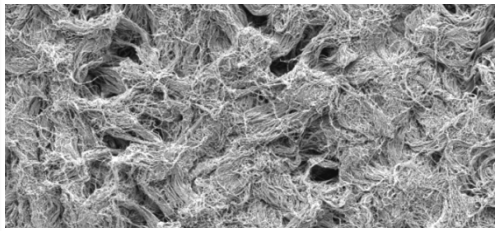
Reach ~6 clo (600 in^3/oz fill power)

Problem Statement

- Goose down is one of the best insulating material but it is expensive, ….
- An affordable , non-allergenic synthetic down, with a similar high fill power could be more widely used in personal thermal management
- High Surface area fibers in a controlled structure can lead to structures heat transfer

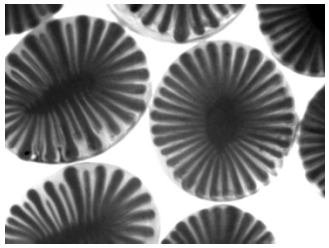
Approach

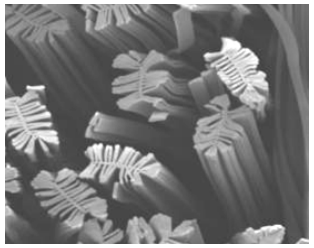
- The key is in find the right technology for trapping air, maximizing compression recovery
- Consolidation control

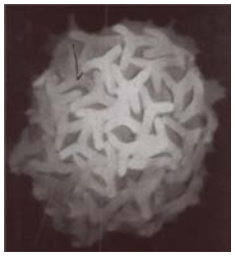


Potential Solutions

- We already have experience with multi-lobal and high surface area fibers







Scientific & Technical Challenges

- Barrier materials for controlling moisture and heat transfer
- Variable loft and porosity,
- Humidity control
- Thermoelectrics
- Surface micro-texture
- Energy harvesting
- Thermal routing around human body
- Adaptive housewrap
- Thermoelectrics …

Thermal autoregulation using nanostructured fabric

Michelle L. Povinelli
povinell@usc.edu

Save the “last 5 degrees”: reduce energy expenditure on building heating/cooling by 25%

Problem Statement

- How can we make clothing that automatically adjusts to heat or cool the wearer?
- How can the efficiency of such a personal heating/cooling system be designed to be higher than the whole-building heating/cooling efficiency?

Approach

- **Thermally-responsive, nanostructured, polymeric fabric**: changes between two states, depending on the body temperature of the user: either reflective or transmissive at thermal infrared wavelengths.
- Leverage iCVD deposition of thermally-responsive polymers to conformally coat nanoparticles and fibers
- Use photonic modeling to design infrared response

Potential Solutions

- garments with adjustable insulation properties
- garments made up of photovoltaic fibers for active heating
- wireless sensor/power transfer networks for targetted heat delivery

Scientific & Technical Challenges

- achieving broadband material response across entire thermal infrared range
- reducing manufacturing cost to levels comparable with current garments
- reducing energy expenditure associated with manufacturing and disposal to achieve favorable overall energy balance
- designing for individual variations in personal temperature comfort levels