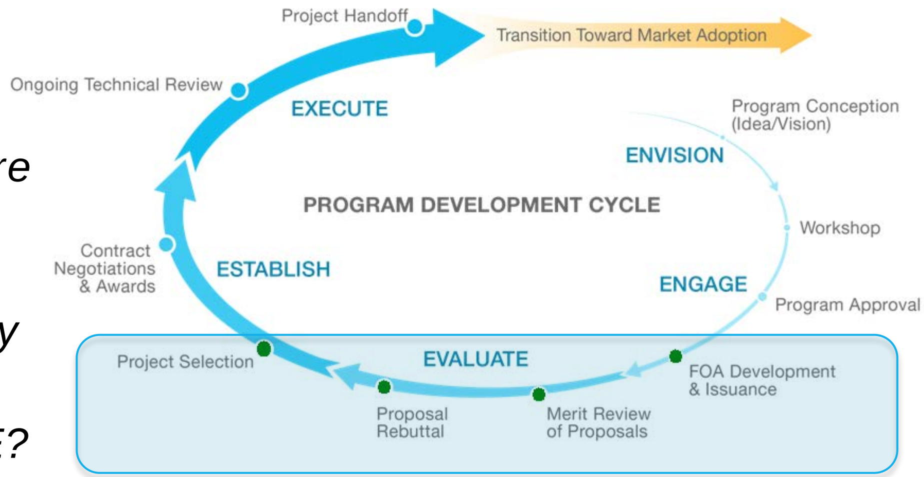
BREAKOUT Instructions Sheet:

Day 1: **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 #4

First Name	Last Name	Company/Organization
Howard	**Branz**	**ARPA-E Moderator**
Ashok	**Gidwani**	**Booz Allen Hamilton**
Roger	Barker	North Carolina State University
Neal	Herring	UTRC
Davion	Hill	DNV Research & Innovation
Satish	Kumar	Georgia Institute of Technology
Karen	Leonas	North Carolina State University
Tasha	Lewis	Cornell University
Jiangyu	Li	University of Washington
Huiju	Park	Cornell University
Lianne	Sandberg	NanoSonic, Inc.
Lloyd	Tripp	AFRL
Youjiang	Wang	Georgia Tech
Hui	Zhang	Berkeley

Individualized Clothing Microclimate Systems that Work

Dramatically decrease building energy consumption through systems engineering, better metrics and integration of advanced technologies into clothing for personal heating and cooling for indoor spaces

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Problem Statement

Many clothing-based technologies promise to extend the thermal comfort band across an expanded temperature range(60-80F), without need for building environmental heating and cooling. In spite of this potential, they are not commonly used or considered for ordinary clothing.

Thermal comfort is a highly personalized perception affected by many clothing and environmental factors. How much clothing insulation, or cooling is actually needed to significantly affect perceived differences in human thermal comfort in the 60-80F neutral range?

What are the optimum systems level approaches for incorporating new technologies to affect a better practical outcome?

Approach

Advanced **models & instrumented manikins for optimizing advanced materials & active cooling technologies** for this application

Human subject studies to better understand **clothing effects on human thermoregulation & perceived comfort** in indoor environments maintained at 60-80F.

Prototype clothing systems incorporating concepts for localized active conductive or convective heating & cooling using electronics

Understanding of clothing or body based **localized heating & cooling on perceived human thermal comfort** & well being

Validation studies demonstrating **practical & workable solutions**

Potential Solutions

Better Metrics to assist the design and evaluating of new textile materials and novel electro-mechanical devices for clothing heating or cooling

Enhanced approaches to clothing thermal comfort through better **understanding of individualized personal response to environments**

Effective **integration of advanced active cooling technologies** into clothing ensembles.

Impact: **identification of workable technologies leading to consumer acceptance of clothing based solutions** to reducing building heating and cooling

Long term: development and validation of **advanced technologies for active localized cooling or heating of garments for significant energy savings**

Scientific & Technical Challenges

Development of **individualized thermoregulation models that can learn from user feedback**

Optimization of the **models for the temperature ranges and metabolic rates encountered in indoor building environments**

Identifying promising technologies for providing power to operate electronic devices for heating/cooling

Demonstrating human acceptance of designed systems

Minimizing anticipated production cost

United Technologies Research Center

Personal Thermal Management for Reduced Building Energy Consumption

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Improved cooling effectiveness and personalized control provides 10% HVAC energy reduction

Problem Statement

- High cost and poor utilization of space cooling:
  - <2% of energy in buildings provides comfort to occupants.
  - 1/3 of building population is comfortable. Others too cool or warm

- Short-term impact: Localized cooling/heating enables set-point relief [10% energy reduction]
- Long-term impact: New HVAC architectures that minimize space cooling.

Approach

- Improve utilization of cooling energy by using local delivery (microclimate) and personalized comfort
- Physiology of thermal comfort – thermodynamic cooling and personal comfort are not the same thing
- Exploit microclimate/macroclimate interaction and natural air movement to maximize effectiveness of personal cooling solutions
- Rigorous model-based design approach needed for seamless insertion and sustained adoption

Potential Solutions

- Use building level HVAC for bulk thermal management with relaxed thermal set points
- Wearable cooling solutions developed for HAZMAT, soldier cooling, and EVSS.
- Thermal management of equipment such as office chairs and desks
- Technologies: Electrocalorics, miniature heat pumps, thermoelectric systems.
- Operational: Stratified thermal zones (Floor 1 is cool, Floor 2 is warm)

Scientific & Technical Challenges

Technical Risks

- Micro-Macroclimate Interaction
- Moisture Handling
- Cost
- Scalability
- Efficiency, Size and Weight

Non-Technical Challenges

- Logistics
- Adoption

Modular Smart Thermal Storage Materials for Human Comfort

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Remove seasonality of HVAC operation, reduction of HVAC over-capacity (-20%), reduce energy intensity of peak heating/cooling degree days

Problem Statement

- Thermal management is a question of human comfort.
- Comfort includes lack of restriction (clothing), uniform temperature (no cold hands or toes), consistent temperature.
- To heat/cool, it is a question of thermal storage and available power/energy. Thermal storage can be short term leveling (power) or long term leveling (energy).
- Clothing and buildings try to do both. Older buildings have poor insulation. Retrofits are expensive. Capacity utilization is an issue. Clothing and style is a personal value. It is a one size fits all solution, with enough variation to cause discomfort to humans.

Approach

- Non invasive, intelligent, thermal storage materials for human comfort in multiple industries.
- Integration of PCM's and smart sensing controls with energy harvesting capability
- Materials that can be used in clothing or building materials

Potential Solutions

- Occupancy-sensitive thermal storage
- Energy harvesting:
  - PowerLeap (piezo EH)
  - Genziko (piezo EH)
- Upstream textile and materials solutions for white label production (i.e., PolarFleece, recycled PET)
- Multifunctional smart materials
- Integrated active controls for active, smart, thermal materials

Scientific & Technical Challenges

- Cost
- Fashion and personal taste
- Longevity

Textile fibers that can provide heating and cooling

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Value Proposition: Reduce US energy consumption by 1%

Problem Statement

- Can textile quality (aesthetics, color, feel, durability, mechanical properties etc) fibers be made that can provide heating in winter and cooling in summer?

Approach

- Process fibers with nano and other materials
- Some of the nano materials synthesis, their dispersion in polymers, as well as their fiber spinning technologies are now reasonably well developed.

Potential Solutions

- Process polymeric textile fibers containing heating element.
- Process polymeric textile fibers containing cooling element.

Scientific & Technical Challenges

- Main challenge will be to bring the material and processing cost at the level that makes economic sense.

NC STATE UNIVERSITY

Ensuring Adoption of Personal Thermal Management Systems by Users through Thoughtful Design, Development, and Implementation.

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Problem Statement

- Provide individual apparel options that are accepted (adopted) and used resulting in personal thermal management systems and effective in meeting daily/routine activities.
- Both short term and long term will reduce energy use; controlling the near environment of the user will eliminate the need to control the environment of large spaces.

Approach

- Design apparel that is functional, aesthetically pleasing, and provides individual thermal management capabilities. Observation and surveys to determine needs; identification of potential materials that are effective in meeting needs and strategic use of these materials leading to adoption and use.
- New materials that change to meet various environmental conditions; technology to qualify/quantify activities; technology to gather information (surveys); technology to analyze results.

Potential Solutions

- Phase change materials; digital printing for targeted finish locations; input from users; introduce to market in planned way to target adopters.

Scientific & Technical Challenges

- Design fails to meet users needs (function, aesthetic, thermal management) and therefore there is little to no adoption of product.

Addressing Risks for Advanced Clothing Concepts: The Consumer Experience

Attitudes towards innovation, usability, and "fashionability" will influence consumer intent to adopt advanced clothing concepts for personal thermal management

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Problem Statement

- Introduction of new technology, especially in a wearable format does not guarantee end-user adoption. What are the inhibitors of adoption?
- Collaborative development of thermal management concepts will increase behavioral intent of end-users to adopt a personal thermal management system

Approach

- User experience approach
- Both a qualitative and quantitative data collection: focus groups interviews, cognitive walk-throughs, observations, and questionnaire (demographics, psychographics, wearability)

Potential Solutions

- Visualization tools for consumer evaluation of concepts
- Digital "storyboards" to capture consumer knowledge and concepts
- Convey ideas visually instead of verbally

Scientific & Technical Challenges

- Lack of suitable prototypes for consumer evaluation
- Functional prototypes lacking in usability and "fashionability"

Flexible thermoelectric nanocomposites as smart textile

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Problem Statement

- Seek material solution to enable effective personal thermal management for the reduction of building energy consumption.

Approach

- Development of polymeric thermoelectric nanocomposites
- Fabrication of flexible thermoelectric module
- System integration of personal thermal management
- Modeling, simulation, and analysis

Potential Solutions

- Develop high performance thermoelectric nanocomposites that are flexible, efficient, and cost effective, which can be used as smart textile for personal thermal management.

Scientific & Technical Challenges

- Design and processing of multi-phase nanocomposites satisfying multiple objectives that often compete with each other
- Integrate the personal thermal management system that is efficient while retaining personal comfort.

Personal Thermal Management Clothing System

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To develop a highly efficient thermal regulating underwear, capable of controlled heating or cooling of at least 15 Watts, without sacrificing wearing comfort and overall appearance.

Problem Statement

- How would you frame the problem?
  - Limited thermal regulation in existing material/clothing
  - Difficulty in creating cooling effect without sacrificing wear comfort and overall appearance.
- If success is attained:
  - Expansion of neutral-band of building by at least 4ºF in each direction.
  - Save more than 1% of the total energy consumed in US.

Approach

- Integration of materials and functional apparel design.
- Use of micro-electronics
- Use of soft actuators
- Use of sweating fabric manikin technology.
- Building on the understanding of heat and mass transfer through clothing.
- Building on the understanding of clothing physiology.

Potential Solutions

- Temperature regulating fabrics (Fabrics with variable transport properties).
- Conductive yarns for heating
- Micro-electronics
- Soft actuators
- Direct heating from wireless source.
- Mechanisms to create air flow inside clothing to enhance mass and thermal transport.

Scientific & Technical Challenges

- Increased weight.
- Increased wearing discomfort.
- Unacceptable overall appearance.
- Consumer acceptance.
- Need for power supply.
- Limitation of temperature regulating fabrics.
- Development of mass production methods for new types of thermal regulating garments

Hybrid Personal Comfort Garments for Indoor Use

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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.

Textiles with multiple geometric and physical stable states

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Fibers/fabrics/clothing with multiple geometric and physical stable states provide drastically wider range of thermal regulating capabilities.

Problem Statement

- How would you frame the problem?
  - Clothing as part of the overall thermal management system, offering comfort to the wearer over a wider range of surrounding conditions (T, RH).
- If success is attained, what are the potential short-term and long-term impacts it will have on US energy consumption?
  - Reduction of energy needs after broad adoption by consumers

Approach

- What R&D would you like to carry out in pursuit of a personal thermal management system?
  - Textiles with multiple geometric and physical stable states according to T/RH.
- What are the key enabling/emerging technologies and/or recent achievements that support the feasibility of your approach?
  - Phase change materials provide heat absorption and release
  - Stable geometries governed by mechanics

Potential Solutions

- Make a prioritized list of potential candidate technologies that address the problem statement. Please include candidate technologies that are beyond your own research.
  - Active control with powered mechanisms.
  - Passive control without power supplies.
  - Changes in fabric's "bulk"
  - Changes in the thermal properties of the clothing material.
  - Phase-change "additives" for heating/cooling

Scientific & Technical Challenges

- What are the major risk-factors that may prevent success, prioritize your list?
  - Developing/adapting enabling technologies
  - Integration of enabling technologies
  - Durable, easy care
  - Garments appealing to consumers
  - Wide adoption by consumers

Thermal Physiology and Comfort

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Insert value proposition statement for your technical approach = *X* clo/°F, *Y* Watts Thermally dissipated, *Z* kWh saved per year…

Problem Statement

- Personal variation makes current uniform space conditioning unsuccessful
- Information needed on how to design personal systems—wearable or workstation-based
- How do people respond to combinations of local thermal stimuli?
- *Potential:* future thermal stimulus devices will be scalable and apply across whole building stock

Approach

- Obtain thermal sensitivities of various body regions to mini local cooling/heating stimuli
- Develop devices to provide cooling and heating within clothing and workstation furniture

Potential Solutions

- Devices using convective cooling
- Contact devices using conductive heating and cooling
- Devices using focused radiation
- Devices controlling moisture transport from skin

Scientific & Technical Challenges

- Making devices that are practically and economically feasible for building occupants