U.S. Department of Energy
Advanced Research Projects Agency – Energy

Request for Information (RFI)
DE-FOA-0000938
on
Personal Thermal Management Systems to Reduce Building Energy Consumption

Objective:

ARPA-E seeks input from researchers and technologists from a broad range of fields and disciplines to address advanced clothing and textiles with enhanced thermal management capabilities. These technical solutions have the potential to enable a wider temperature set point range for buildings, thereby reducing the energy consumed to heat or cool them, while maintaining or improving personal thermal comfort for building occupants. The information you provide may be used by ARPA-E in support of program planning. THIS IS A REQUEST FOR INFORMATION ONLY. THIS NOTICE DOES NOT CONSTITUTE A FUNDING OPPORTUNITY ANNOUNCEMENT (FOA). NO FOA EXISTS AT THIS TIME.

Background:

Space heating and cooling of buildings represents more than 12% of all energy used domestically[1], about 12 Qbtu of energy annually (primary). The electricity usage of commercial and residential buildings accounts for more than 70% of all electricity used in the United States. This represents 40% of our nation's total energy bill,[2] and contributes to almost 40% of the nation's carbon dioxide emissions.[3] The large energy consumption associated with space heating and cooling is primarily driven by the need to provide a comfortable range of temperatures to the building's occupants. In practice the neutral-band is usually between 71 and 75°F[4], the temperature range between set points where no action is taken by the building's heating and cooling systems. This practice is tighter than the ANSI/ASHRAE standards with acceptable target temperatures within appropriate humidity levels of 68°F during the heating season and 76°F during the cooling season, which is deemed satisfactory for 80% of the occupants.[5]

Due to the potential for large energy savings, there is ongoing research to improve building heating and cooling efficiency. Technologies under development include, but are not limited to,

[1] Buildings Technologies Program Energy Efficiency and Renewable Energy U.S. Department of Energy: 2011 Buildings Energy Data Book, March 2012.
[2] U.S. Energy Information Administration. *Annual Energy Review 2013*. April 2013.
[3] U.S. Environmental Protection Agency, Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990 – 2010, April 15, 2012.
[4] T. Hoyt et al., Energy savings from extended air temperature setpoints and reductions in room air mixing,, Proceedings of International Conference on Environmental Ergonomics (2009) 608-611.
[5] ANSI/ASHRAE Standard 55-2010, Thermal Environmental Conditions for Human Occupancy.

geothermal heat pumps, heat exchangers, new working fluids, and air conditioning units. In addition, building envelope research focuses on improvements in insulation. Even more advanced solutions are being pursued such as walls with variable insulation that modulate the thermal flow in and out of building structures.[6,7]

Expanding the neutral-band can significantly reduce energy use for building heating and cooling. It is estimated that by expanding this neutral-band by as little as 4°F in each direction, energy consumption can be reduced by an average of more than 10% regardless of the building location.[4] That savings corresponds to more than 1% of the total energy consumed by the United States.

In order to enable this strategy of expanding the neutral-band, local, in particular, personal environmental control is necessary to ensure an occupant's thermal comfort. Such personal control also has the additional benefit of improving the percentage of occupants who will achieve thermal comfort. Approximately 20% of all building occupants do not achieve thermal comfort, due to current building control methods that lack the ability to deliver variable temperatures with high spatial resolution.[8] In general, building thermal controls are not refined enough to combat this personal comfort issue due to noise within feedback loops between the individual occupants and the building infrastructure. Inefficient feedback loops generally lead to inefficient buildings that are over-heated in the winter and over-cooled in the summer.

In the context of building energy consumption, the occupants have largely been treated as thermally static. However, work has been undertaken for advancing personal comfort systems. Based on physiological modeling, researchers have proposed the deployment of feet warmers, miniaturized desk fans, and chairs with embedded heaters and fans to improve the thermal comfort for occupants in an office environment. Experiments utilizing these personal comfort devices have shown that occupant comfort can be maintained while the building temperature set points are expanded as far as 61 to 84°F.[9] Such technologies could have a large impact on the United States' energy consumption. On the other hand, solutions that are more portable with the building occupants, such as personal garments, will complement these technologies and realize the full potential of energy savings of personal thermal management systems.

Personal garments are part of the thermal comfort system for an individual. This fact is well recognized in textile and apparel research. Specifically, extensive research has focused on improving the thermal regulation abilities of garments for selected occupations where thermal stress to the person is more severe. These include athletes, firefighters, soldiers, surgeons, farmers, policemen, and astronauts. Advanced technologies such as various forms of breathable membranes, sweat wicking fabrics, and even phase change materials are now

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[6] F. Kuznik et al., Renewable and Sustainable Energy Reviews, 15(1) (2011) 379-391.
[7] Department of Energy, Energy Efficiency Renewable Energy, Building Technology Office, https://www1.eere.energy.gov/buildings/technologies/building_envelope_research.html, accessed 5/30/2013.
[8] P. Fanger, The Environmentalist, 6(4) (1986) 275-278.
[9] E. Arens, Defining and Improving Personal Comfort: in the News and in the Lab, *Centerline*, Center for the Built Environment (CBE), Winter 2013, 3-5.

appearing in everyday clothing.[10] Little effort has been devoted to developing adaptive clothing solutions to improve the thermal comfort of building occupants that would enable an expansion of the neutral-band and reduction in building energy consumption. This lack of effort can be partially attributed to the common belief that clothing is a very personal choice and garments are generally purchased based on style rather than their inherent thermal management attributes. ARPA-E posits that this reason alone does not constitute an insurmountable barrier to the adoption of adaptive clothing.

ARPA-E is thus seeking input from the broad research and development community with regard to developing personal comfort systems, in particular, advanced clothing and textiles, to enable a wider temperature set point range for buildings while maintaining or improving personal thermal comfort. Of paramount importance is for the systems to be as transparent to the consumers as possible. In addition, insights that leverage the well-defined commercial and residential building environment are strongly encouraged. Finally, ARPA-E is looking for areas of innovation that leverage recent advancements in polymeric materials, nanomaterials, thermal transport and storage, and other adjacent scientific fields.

Purpose and Need for Information:

The purpose of this RFI is solely to solicit input for ARPA-E consideration to inform the possible formulation of future programs intended to help reduce the total energy used to heat and cool buildings and structures. Information obtained may be used by ARPA-E on a non-attribution basis. This RFI provides the broad research community with an opportunity to contribute views and opinions regarding novel adaptive clothing solutions. Based on the input provided to this RFI and other considerations, ARPA-E may decide to issue a formal FOA for this area. If a formal FOA is issued, it will be issued under a new FOA number. No FOA exists at this time. ARPA-E reserves the right to never issue a FOA in this area.

REQUEST FOR INFORMATION GUIDELINES:

Comments in response to this RFI should be submitted in PDF format to the email address ARPA-E-RFI-Textiles@hq.doe.gov by **8:00 PM Eastern Time on July 26, 2013.** ARPA-E will not review or consider comments submitted by other means. Emails should conform to the following guidelines:

- Please insert "Responses for RFI for FOA DE-FOA-0000938" in the subject line of your email, and include your name, organization, email address, and telephone number in the body of your email.
- Respondents are requested to include the following information as part of the response to this RFI:
    - Company/Institution name;
    - Individual contact name and title;

[10] J. Hu et al., Smart Mater. Struct. 21 (2012) 053001.

- Mailing address;
  - Phone number;
  - Email address;
  - Type of company/institution (e.g.. university, non-governmental organization, small business, large business, federally funded research and development center (FFRDC), government-owned/government-operated (GOGO)); and
  - Area of expertise.
- **QUESTIONS:** ARPA-E encourages responses that address any subset of the following questions of relevance to the respondent.

  I. Transformational Technologies for Next Generation Textiles:

  1. What are potential technical approaches to enhancing personal comfort while reducing building energy consumption? A few examples are provided here for guidance.
     - i. Personal comfort triggered local control (clothing sensors)
     - ii. Thermally adaptive clothing
     - iii. Local personal comfort system that is not clothing, e.g., footwear, other personal apparel, as well as office furniture and footwear
     - iv. Passive clothing solutions: variable loft and porosity, humidity control
     - v. Active clothing solutions:
       - a. Mechanisms to create air flow inside clothing to enhance mass and thermal transport
       - b. Directed heating from wireless sources
       - c. Energy harvesting; Can energy harvesting, using either applied energy to the system or using energy already present in the local environment, be implemented through electromechanical, microelectromechanical systems, nanotechnological approaches, or other means that are based on either electrodynamic, piezoelectric, thermoelectric, or other effects, and be applied to either sensors or thermal management?
       - d. Thermal routing around human body to promote thermal comfort
  2. What are the gaps in materials and processing technologies?
  3. What are the gaps in physiological and thermal modeling of personal garments and how can these be integrated with thermal modeling of buildings?
  4. In the thermally adaptable clothing area, why has the current research not translated into indoor clothing needs? What are the scientific

advances in recent years that make the topic ripe for innovation now? A few examples are provided here for reference:

   i. Phase change materials
   ii. Bio-inspired materials and approaches
   iii. Shape memory polymers/alloys
   iv. E-textiles

II. Technological and Economic Risk Factors:

1. Should both passive and active solutions be considered? What are the energy balance trade-offs at the garment-level?
2. Is adjustable insulation alone a sufficient and technically feasible solution?
3. What are the unique features of an indoor environment that can assist in the development of a solution?
4. What solutions seem to be the most robust and cost effective given the application demands?
5. What expectations must be met before a solution can transition into commercial markets?
6. What are the potential risk factors, e.g, transparency to users, cost, durability, energy supply for active solutions, etc. and how can they be overcome them?
7. What are the economic barriers to consumer adoption, or in other word, does the new solution need to achieve cost parity with today's commercial garments? How much additional cost can be tolerated for advanced clothing concepts, give examples if possible?
8. What are the social and behavioral risks to adoption for advanced clothing concepts? What factors must be demonstrated to enable adoption?

III. Coalescing a Community:

1. What communities should be engaged in the discussion, for example, researchers in textile, apparel design, footwear, physiology, thermal engineering, building science, behavioral science, material science?
   i. Clothing for extreme uses (medical, firefighter, soldiers, athletes…)
   ii. Clothing designs to better manage thermal comfort
   iii. E-textiles

- Responses to this RFI are limited to no more than 10 pages in length (12 point font size).

- **<u>Responders are strongly encouraged to include preliminary results, data, and figures that describe their potential methodologies.</u>**
- Respondents should not include any information in the response to this RFI that might be considered proprietary or confidential.

ARPA-E will not pay for information provided under this RFI, and there is no guarantee that a project will be supported as a result of this RFI. This RFI is not a FOA, and ARPA-E is not accepting applications for financial assistance under this RFI. Responses to the RFI will not be viewed as any commitment for the respondent to develop or pursue the project or ideas discussed. ARPA-E may decide at a later date to issue a FOA based on consideration of the input received from this RFI.

No material submitted for review will be returned and there will be no formal or informal debriefing concerning the review of any submitted material. ARPA-E reserves the right to contact a respondent to request clarification or other information relevant to this request. All feedback provided will be taken into consideration, but ARPA-E will not respond to individual submissions or publish publicly a compendium of responses.