*Nanoporous fabrics could keep you cool*



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# Nanoporous fabrics help cooling via thermal radiation

**Svetlana V. Boriskina**
*Department of Mechanical Engineering, Massachusetts Institute of Technology, Cambridge, MA 02139, USA*
Email: sborisk@mit.edu

Convection, conduction and thermal radiation all play important role in the personal thermal management. From the early days when animal skins were the season's fashion till modern times, clothes have been typically engineered for comfort in cold environment by tailoring their thermal conduction. Air pockets in feathers, furs and woolen fabrics help to reduce thermal conduction and to keep warmth inside. Cooling effect is however much harder to achieve without the use of external active devices such as fans, air conditioners or wearable thermoelectric coolers. The wicking technology used in the modern athletic apparel to enhance convective cooling is not ideal for everyday clothes, as it only works once perspiration occurs. On page XX of this issue, Hsu *et al.* (*1*) demonstrate a passive way to cool an object by a few degrees by simply allowing thermal radiation to pass efficiently through a nanoporous fabric. This demonstration opens the possibility to develop new wearable technologies for personalized cooling and paves the road to significant energy savings through reduced use of air conditioning.

Human body is an almost perfect emitter of thermal radiation in the mid-infrared spectral range. However, conventional fabrics block infrared waves by partially reflecting them and partially absorbing the thermal energy. The stark variations in the intensity of the thermal emission from the bare skin and through clothes can be easily observed in photos taken with an infrared camera (see the Figure, panel A). Therefore, clothes made from fabrics that are transparent to the infrared waves emitted by the skin offer an opportunity to shed energy via radiation (*2*–*4*). Transparent clothes might sound like an odd idea though, and thus the challenge is to keep the fabric opaque for the visible light that human eyes are sensitive to while making it transparent for infrared radiation.

A simple solution to this dilemma is offered by the Mie theory of resonant scattering from objects with sizes either comparable to or much smaller than the wavelength of the propagating electromagnetic field. This is the same physical effect that is behind the blue color of the sky, which is caused by the scattering of the short wavelength part of the solar spectrum by the small molecules of the atmosphere. Likewise, fabrics with pore sizes that are comparable on average to the wavelength of visible light (400-700 nm) scatter visible light strongly and make the fabric opaque to human eyes. However, if the pore sizes are much smaller than the body infrared radiation wavelength (7-14 micron), such fabrics are still highly transparent to the thermal emission (see the Figure, panel B) (*2*).

Hsu *et al.* (*1*) used a commercially available polyethylene material NanoPE, which has interconnected pores 50-1000 nm in size (see the Figure, panel C), to experimentally demonstrate the radiative cooling effect. Their spectral transmission measurements revealed that the nanoPE exhibits over 90% total infrared transmittance for wavelengths longer than 2 μm and at the same time is completely opaque in the visible due to strong nanopore scattering. The ideal size distribution of the nanopores sets this material apart from the conventional fabrics such as those weaved from cotton or polyester fibers with sizes comparable to the wavelength of the body thermal emission (see the Figure, panels D and E).

While polyethylene is far from being a conventional material for making clothes, it has another advantage of being mostly absorption-free in the mid-infrared spectral range owing to the absence of C–O, C–N and S=O stretching atomic bonds typical for other textile materials. To increase the fabric comfort, the authors modified the material to improve its breathability and to add water wicking functionality by chemically modifying the fabric to be hydrophilic. Clothes fabricated from such infrared-transparent textile could allow for air conditioning setpoints to be set higher than usual while maintaining the same level of personal thermal comfort. Depending on the climate, a 1-4 °C increase in the AC setpoint temperature can save up to 45% of the energy required for the building cooling (*5*).

Although Hsu *et al.* provide the first experimental demonstration of the artificial cooling fabrics designed for humans, the nature already offers analogous solutions for the animal thermal control. One striking example of such natural nanotechnology is the skin hair cover of the Saharan silver ant (see the Figure, panel F) (*6*). The hairs are fine enough to strongly scatter and reflect sunlight to avoid overheating by absorption. At the same time, they are transparent at infrared wavelengths, letting the insect shed heat via thermal radiation. Removal of the hairs increased the ant temperature by a couple of degrees and clearly demonstrated the success of such nanophotonics solution for the personal thermal management applications.

However, much remains to be done to bring the radiative cooling technology to the market for human consumers. Other materials need to be explored or synthesized that would provide the required level of infrared transparency combined with a higher level of personal comfort. Fabrics weaved from fine fibers (*2*) rather than those fabricated by introducing nanopores into continuous films can open possibilities for using conventional textile fabrication technologies and equipment to facilitate the technology-to-market transition. Infrared-transparent dyes and pigments also need to be investigated and synthesized to maintain the cooling functionality of colored fabrics.

The approach to the smart fabrics design used by Hsu *et al*. holds promise for thermal control applications way beyond personalized cooling. The same conceptual approach can help to improve thermal management of tents, buildings and vehicles (*3*, *7*, *8*), and will undoubtedly lead to many exciting advances of passive cooling technologies resulting in significant energy savings.

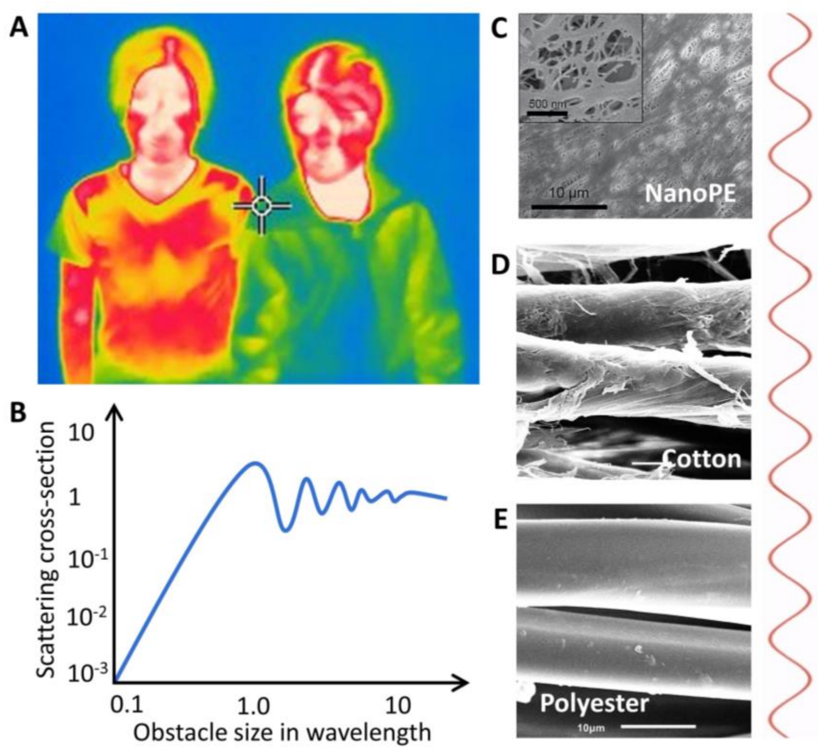


**Figure: Oh the difference clothes can make**. (A) An image made with an infrared camera illustrates how the thermal emission from a body can be either blocked by clothes or facilitated by using infrared-transparent fabrics (image: I. Puscasu, FLIR & S.V. Boriskina, MIT). (B) Scattering cross-section of an obstacle varies greatly depending on whether it is smaller or larger than the photon wavelength. (C-E) Scanning electron microscopy images of nanoPE (C) (image: Hsu *et al*.), cotton (D) and polyester (E) (images: J. Loomis, Auckland University) fabrics reveal the average size of the obstacle relative to the infrared wavelength (illustrated as the sinusoid on the right).

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Possible second figure if length adjustment is required:

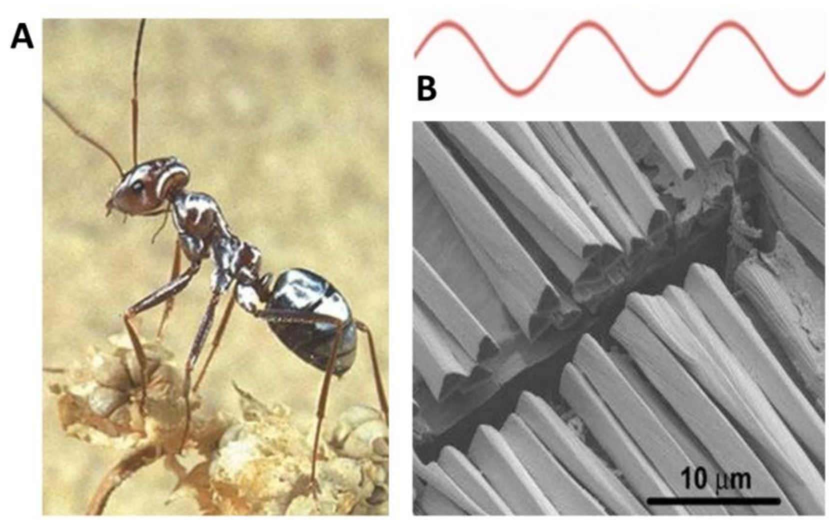


**Figure: Natural nanotechnology for personal thermal management via radiation**. (A) Fine hairs covering the body of the Saharan silver ant reflect sunlight to avoid overheating. (B) The scanning electron microscopy image of the hairs reveals that they are thinner than the infrared emission wavelength (shown on top), which lets the ant shed energy through radiation that passes freely through the hair layer.