Stanford Engineers Invent High-Tech Mirror to Beam Heat Away from Buildings into Space

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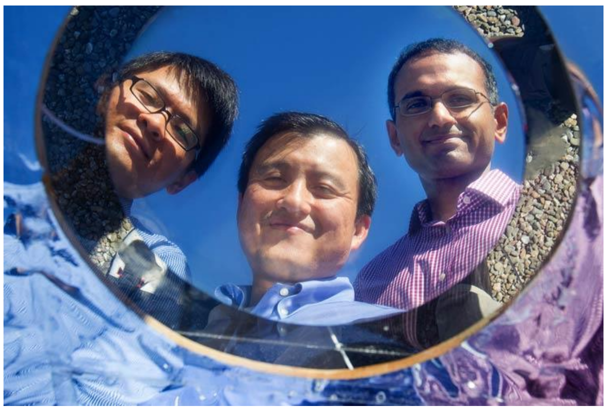

Doctoral candidate Linxiao Zhu, Professor Shanhui Fan and research associate Aaswath Raman are members of the team that invented the breakthrough energy-saving material.

A new ultrathin multilayered material can cool buildings without air conditioning by radiating warmth from inside the buildings into space while also reflecting sunlight to reduce incoming heat.

By Chris Cesare

Stanford engineers have invented a revolutionary coating material that can help cool buildings, even on sunny days, by radiating heat away from the buildings and sending it directly into space.

A team led by electrical engineering Professor Shanhui Fan and research associate Aaswath Raman reported this energy-saving breakthrough in the journal *Nature*.

The heart of the invention is an ultrathin, multilayered material that deals with light, both invisible and visible, in a new way.

Invisible light in the form of infrared radiation is one of the ways that all objects and living things throw off heat. When we stand in front of a closed oven without touching it, the heat we feel is infrared light. This invisible, heat-bearing light is what the Stanford invention shunts away from buildings and sends into space.

Of course, sunshine also warms buildings. The new material, in addition dealing with infrared light, is also a stunningly efficient mirror that reflects virtually all of the incoming sunlight that strikes it.

The result is what the Stanford team calls photonic radiative cooling – a one-two punch that offloads infrared heat from within a building while also reflecting the sunlight that would otherwise warm it up. The result is cooler buildings that require less air conditioning.

"This is very novel and an extraordinarily simple idea," said Eli Yablonovitch, a professor of engineering at the University of California, Berkeley, and a pioneer of photonics who directs the Center for Energy Efficient Electronics Science. "As a result of professor Fan's work, we can now [use radiative cooling], not only at night but counter-intuitively in the daytime as well."

The researchers say they designed the material to be cost-effective for large-scale deployment on building rooftops. Though still a young technology, they believe it could one day reduce demand for electricity. As much as 15 percent of the energy used in buildings in the United States is spent powering air conditioning systems.

In practice the researchers think the coating might be sprayed on a more solid material to make it suitable for withstanding the elements.

"This team has shown how to passively cool structures by simply radiating heat into the cold darkness of space," said Nobel Prize-winning physicist Burton Richter, professor emeritus at Stanford and former director of the research facility now called the SLAC National Accelerator Laboratory.

A warming world needs cooling technologies that don't require power, according to Raman, lead author of the *Nature* paper. "Across the developing world, photonic radiative cooling makes off-grid cooling a possibility in rural regions, in addition to meeting skyrocketing demand for air conditioning in urban areas," he said.

Using a window into space

The real breakthrough is how the Stanford material radiates heat away from buildings.

As science students know, heat can be transferred in three ways: conduction, convection and radiation. Conduction transfers heat by touch. That's why you don't touch an oven pan without wearing a mitt. Convection transfers heat by movement of fluids or air. It's the warm rush of air when the oven is opened. Radiation transfers heat in the form of infrared light that emanates outward from objects, sight unseen.

The first part of the coating's one-two punch radiates heat-bearing infrared light directly into space. The ultrathin coating was carefully constructed to send this infrared light away from buildings at the precise frequency that allows it to pass through the atmosphere without warming the air, a key feature given the dangers of global warming.

"Think about it like having a window into space," said Fan.

Aiming the mirror

But transmitting heat into space is not enough on its own.

This multilayered coating also acts as a highly efficient mirror, preventing 97 percent of sunlight from striking the building and heating it up.

"We've created something that's a radiator that also happens to be an excellent mirror," said Raman.

Together, the radiation and reflection make the photonic radiative cooler nearly 9 degrees Fahrenheit cooler than the surrounding air during the day.

The multilayered material is just 1.8 microns thick, thinner than the thinnest aluminum foil.

It is made of seven layers of silicon dioxide and hafnium oxide on top of a thin layer of silver. These layers are not a uniform thickness, but are instead engineered to create a new material. Its internal structure is tuned to radiate infrared rays at a frequency that lets them pass into space without warming the air near the building.

"This photonic approach gives us the ability to finely tune both solar reflection and infrared thermal radiation," said Linxiao Zhu, doctoral candidate in applied physics and a co-author of the paper.

"I am personally very excited about their results," said Marin Soljacic, a physics professor at the Massachusetts Institute of Technology. "This is a great example of the power of nanophotonics."

From prototype to building panel

Making photonic radiative cooling practical requires solving at least two technical problems.

The first is how to conduct the heat inside the building to this exterior coating. Once it gets there, the coating can direct the heat into space, but engineers must first figure out how to efficiently deliver the building heat to the coating.

The second problem is production. Right now the Stanford team's prototype is the size of a personal pizza. Cooling buildings will require large panels. The researchers say there exist large-area fabrication facilities that can make their panels at the scales needed.

The cosmic fridge

More broadly, the team sees this project as a first step toward using the cold of space as a resource. In the same way that sunlight provides a renewable source of solar energy, the cold universe supplies a nearly unlimited expanse to dump heat.

"Every object that produces heat has to dump that heat into a heat sink," Fan said. "What we've done is to create a way that should allow us to use the coldness of the universe as a heat sink during the day."

In addition to Fan, Raman and Zhu, this paper has two additional co-authors: Marc Abou Anoma, a master's student in mechanical engineering who has graduated; and Eden Rephaeli, a doctoral student in applied physics who has graduated.

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