Making pneumatic thermostats energy efficient

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Resources

Cypress Envirosystems, *www.cypressenvirosystems.com* **Cypress Semiconductor**, *www.cypress.com* **Wikipedia page on thermostats**, *http://en.wikipedia.org/wiki/Pneumatic_thermostat*

In the last decade or so, owners of commercial buildings have relied on building automation systems (BAS) to minimize energy use, with the biggest savings generated from better control over HVAC systems. Now the big buzz is over wireless BAS which, because there is no new wiring involved, should save up to 50% of its initial cost by minimizing installation expenses.

Though BAS is a great idea, unfortunately millions of commercial buildings can't take advantage of it, neither wired nor wireless. That includes most commercial buildings erected before 2000. That's because these buildings use pneumatic thermostats to control heating and air conditioning. Pneumatic thermostats use compressed air actuation and control. They contain no electronics or remote controls and provide no diagnostic data. Pneumatic thermostats employ a simple bimetallic strip to sense temperature and each must be set manually.

The only way to retrofit these buildings with BAS is to cut open walls and ceilings to replace the pneumatics with electric motors and digital controls. This is expensive and disruptive, particularly when such work exposes asbestos and other harmful materials to the building occupants. In other words, it is largely impractical for most buildings.

With a clear need like this, one might think a solution would have been found years ago. One tactic has been to replace the pneumatic thermostat with an wireless electronic version. The typical approach has employed a pulse-width-modulated solenoid (PWM) and microprocessor to wirelessly control it. The problem has been that such systems require battery power, and the constant sampling and pulsing quickly drains the battery. Also, a PWM valve isn't reliable. It can easily clog with water, dirt, or oil, all of which are found in most older pneumatic systems.

Cypress Envirosystems took a different approach with a device called the Wireless Pneumatic Thermostat or WPT. A version of the Wireless Pneumatic Thermostat, or WPT , directly replaces a pneumatic thermostat and turns it into a BAS node.

The WPT enables remote temperature setpoint adjustment by moving a slider lever. In conventional pneumatic thermostats, the slider lever lets occupant control temperature setpoint by adjusting the position of the bimetallic element which in turn is connected to a small air valve. When the room is too warm, the bimetal bends one direction and opens the valve. When it's too cold, the bimetal bends the other direction and closes the valve.

The WPT interacts with the slider lever using a stepper motor that connects to the lever through a cam. The motor itself is off-the-shelf and quite small, measuring about 1×1×2 cm. When the WPT receives a signal to set room temperature, it begins rotating the stepper motor in the correct direction. Optical feedback ensures the stepper motor moves to the correct position.

The WPT also employs a pressure sensor to monitor the air pressure line controlled by the thermostat. The air pressure line serves as a control signal for the building's heating and cooling system. The WPT taps into it via a small tube connected to a MEMS pressure sensor. The WGR monitors air pressure and beams air pressure status back to the BAS.

Electronics in the wireless thermostat stays mostly in "sleep" mode, waking up every 15 minutes to check status and do set-point changes. The heavy lifting is still done by the pneumatic thermostat. This stretches the life of the battery (a standard lithium battery called a CR123a) to as much as five years.

Data passes over a wireless mesh network which uses several repeaters. This network is self-healing (when one path is blocked, another path may be established using different repeaters). In a mesh network, data may go through multiple redundant paths to reach a

central hub. The hub stores historical data and hosts a user Web interface through which one can access specific thermostats. Typical tasks include looking for trends, doing set-point control, and downloading temperature data to Excel.

The hub, called the Green Box, has a built-in server that runs BACNet, the open protocol used in the HVAC industry. The server makes every gauge in the system look like a BACNet object. This lets the hub talk with an existing BAS.

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The radio used in the thermostat wireless node is proprietary to Cypress Semiconductor and was developed more that 10 years ago, with over 26 million units shipped. It was originally used for wireless keyboards and wireless mice. It consumes little power and is immune to noise. It operates on 2.4 GHz -- an unlicensed band, similar to that used by Bluetooth and ZigBee networks.

A Cypress PSoC, programmable system on a chip, serves as the microprocessor. The same architecture used in the WPT now goes into many other wireless, energy-savings devices, including an optical gauge reader, a steam trap monitor, a transducer reader, a battery monitor, and a freezer monitor.

Pneumatic retrofit

It takes about 15 minutes to retrofit the WPT to an existing pneumatic thermostat, including calibration. And return on investment is often significantly shorter than 18 months because the thermostats let older buildings participate in advanced energy savings strategies including deadband setpoint control, ongoing commissioning, and smart grid demand-response schemes for peak load reduction.

For example, Santa Clara County Government and Kaiser Permanente healthcare use thermostats to participate in Pacific Gas and Electric's (PG&E) Automated Demand Response Program, or AutoDR for short. It uses smart grid technology developed by the Lawrence Berkeley National Lab to send Internet demand response signals to customer facilities. The WPT uses these signals to raise the set points on a building's thermostats by a predetermined number of degrees, reducing energy use during peak demands. AutoDR saves money by reducing energy use when electricity is most expensive. Moreover, PG&E also offers substantial incentive payments to customers who participate in the program.

Explains facilities manager Paul Becker of PG&E customer Kaiser Permanente, "It only took five days to install and calibrate 65 WPTs. Now we control set points for all thermostats remotely and have programs in place to control them according to all sorts of variables. We have a true wireless EMS system. We can go online and see every zone and control each one remotely. WPTs also give us powerful diagnostic and troubleshooting tools. We expect to receive almost instant return-on-investment from the PG&E incentives."

Santa Clara County added WPTs on two of its old pneumatic-controlled buildings. "The whole project, including installation, only took eight days and cost about $175,000 for retrofitting 350 thermostats," said Lin Ortega, Santa Clara County utilities engineering program manager. "We made the deadline and received the PG&E incentive of $200,000. Talk about instant ROI. Plus, we figure that we are saving $42,000 annually in electricity for just those two buildings. And then there's maintenance. We used to be out there all the time tinkering with the system. Now we monitor it online. We figure our maintenance expense has been halved from $25,000 annually to $12,500."

The beginning of an idea

The germ of the idea for a wireless retrofit thermostat came from Dan Ginn who sits on the board of Cypress Envirosystems. Ginn runs RSD/Total Control, the largest independently owned parts and equipment refrigeration wholesaler in the West. In this role, Ginn is familiar with the energy wasted in buildings equipped with pneumatic thermostats. One day he pulled aside Cypress Envirosystems CEO Harry Sim to ask if the technology his firm was developing could make old buildings heat and cool more efficiently.

"We scratched our heads and wondered how we were going to do that when so many others had failed," says Sim. "Finally it hit us that a pneumatic thermostat with the bimetallic strip is a pretty darn good design. It's been around for decades. It doesn't need any batteries and it controls the temperature pretty well, so all we had to do was to put a radio on it with a motor to turn the thumb wheel and some sensors for pressure and temperature and a radio. Aside from that, everything else is done by the pneumatic thermostat."

Visible inside a WPT is the motorized slider mechanism, a connection to the pneumatic tube in the existing thermostat, batteries, and LCD read out. The device installs over-top an existing pneumatic thermostat in about 15 minutes.

Visible inside a wireless gauge reader is the two ordinary batteries used to power the wireless network and other electronics used to note temperature from an ordinary dial read and beam this information back to a BAS.

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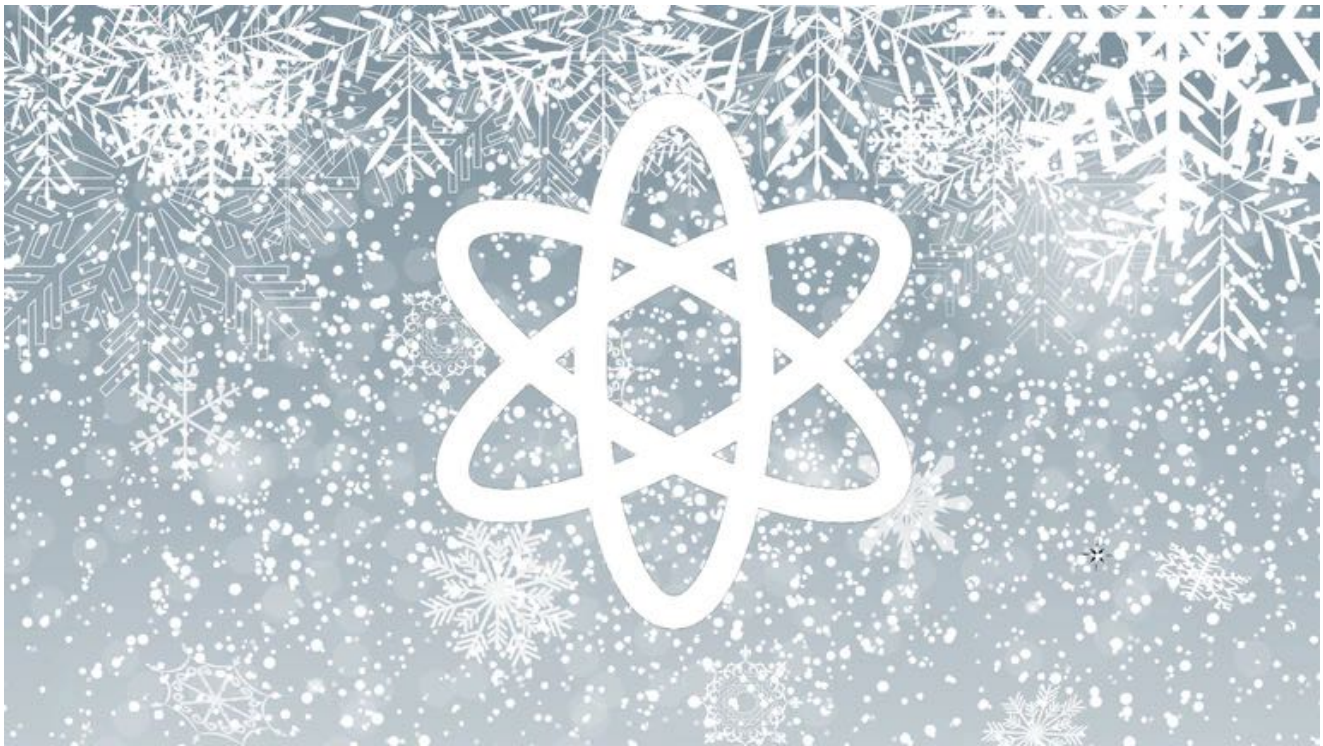
There's apparently little limit to the imaginative ways to explore and exploit the "something for almost nothing" potential of energy harvesting. Researchers at UCLA working with participants at other institutions devised a triboelectric-based energy harvester that creates electricity from falling snow. Their snow-based triboelectric nanogenerator (TENG) uses the fact that falling snow is positively charged and seeks to give up electrons *(Fig. 1)*.
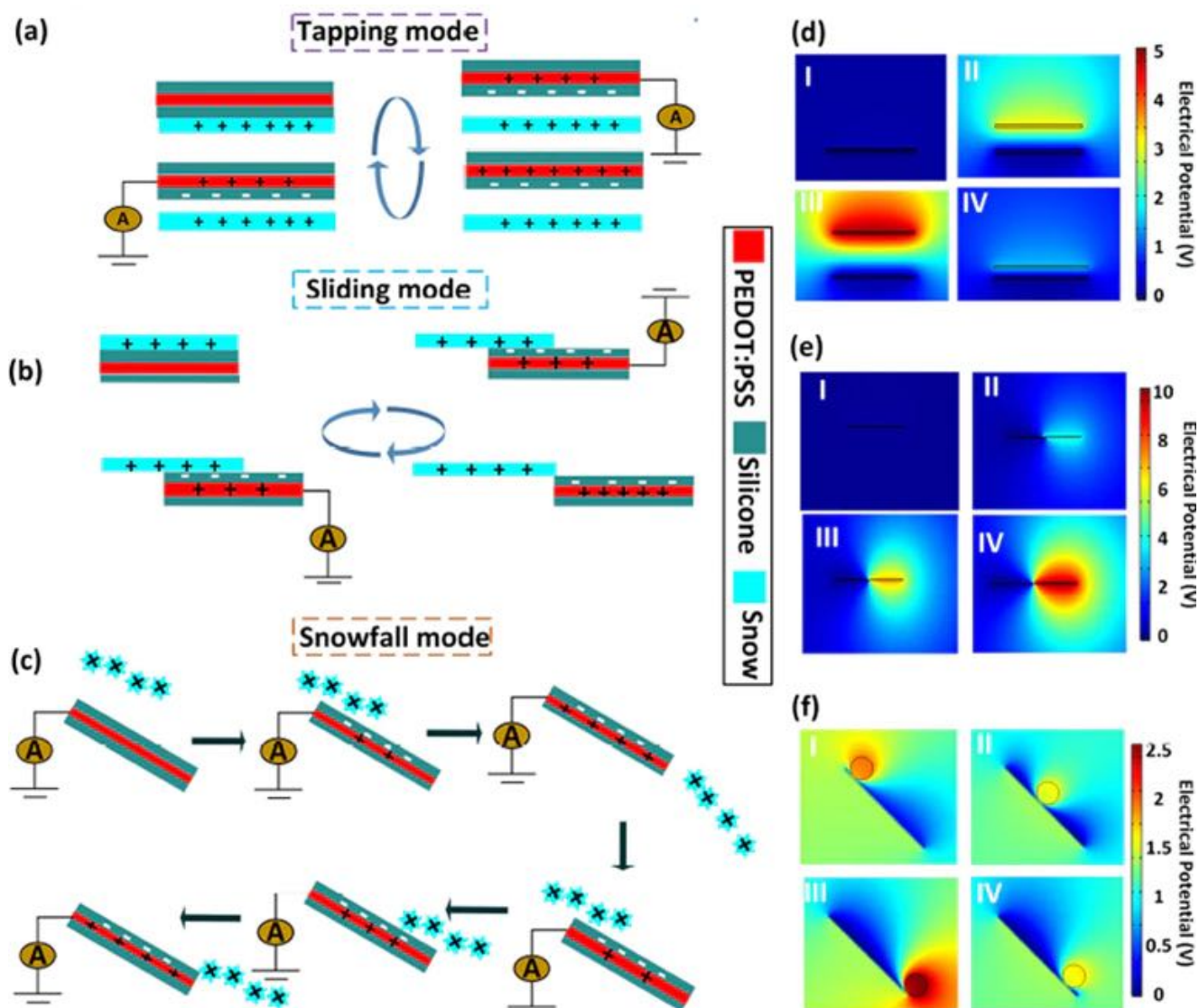
1. The working mechanisms and FEM simulations of a snow-TENG: Schematic illustration showing the working mechanism of a snow-TENG utilizing three different operating modes including tapping, sliding, and snowfall (a, b, c); FEM simulation results for the corresponding operational modes (d, e, f). Finally, triboelectric charges can also be generated when snow falls on the silicone film. (Source: UCLA)

Co-author Maher El-Kady, a UCLA assistant researcher of chemistry and biochemistry, said "Snow is already charged, so we thought, why not bring another material with the opposite charge and extract the charge to create electricity?"

To pair with the falling snow and create the required electron transfer, they needed a suitable negatively charged material. "After testing a large number of materials including aluminum foils and Teflon, we found that silicone produces more charge than any other material," said El-Kady. They then used 3D printing to construct the device, which has a layer of silicone and an electrode *(Fig. 2)*. This allowed them to precisely control the design and deposition of the electrode and triboelectric layer, leading to a flexible, stretchable, and metal-free TENG.
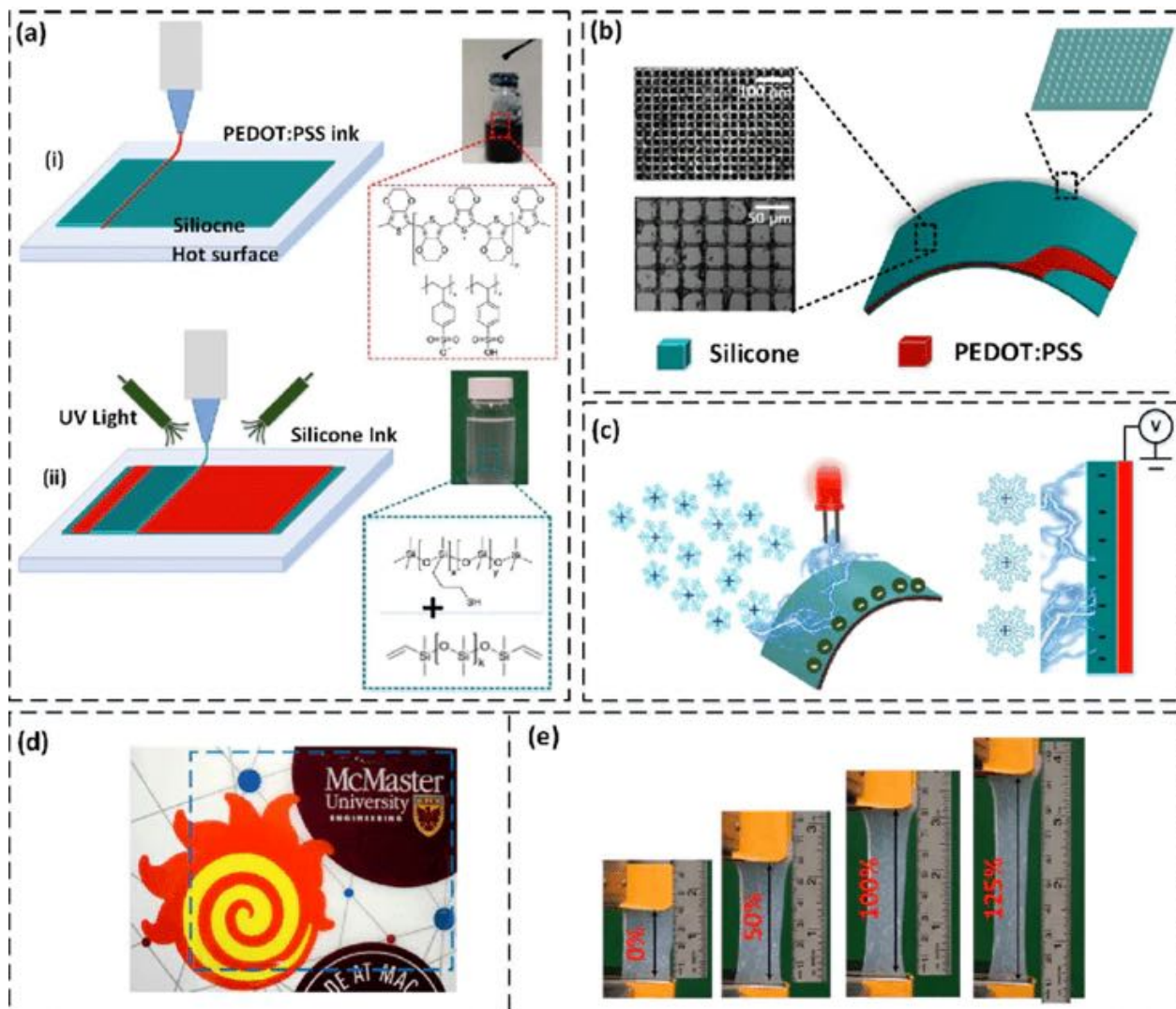
2. The 3D-printing process and architecture along with the optical and mechanical properties of a snow-TENG. Shown is a schematic illustration of the printing process of a snow-TENG (a): printing of a conductive polymer electrode (a-i); inset shows the chemical composition of the ink, (a-ii). On the right is printing of the triboelectrification layer based on UV curable silicone ink; inset reveals the chemical composition of the silicone ink. Next is a schematic illustration of the structure of the device, featuring a micropatterned surface of the UV curable silicone; SEM images on the left are showing the micropattern at different magnifications (scale bars are 100 µm and 50 µm, respectively) (b). The working principle of the device based on snow triboelectrification is shown in (c). In (d) is a photograph showing the high transparency of the silicone layer; the logo of McMaster University in the background can be recognized through the silicone layer. Exposure of the snow-TENG to different stretching conditions is given in (e). (Source: UCLA)

Based on the single electrode mode, the device can generate an instantaneous output power density as high as 0.2 mW/m² (50-MΩ load), open-circuit voltage up to 8 V, and a current density of 40 µA/m² under defined conditions *(Figs. 3 and 4)*.
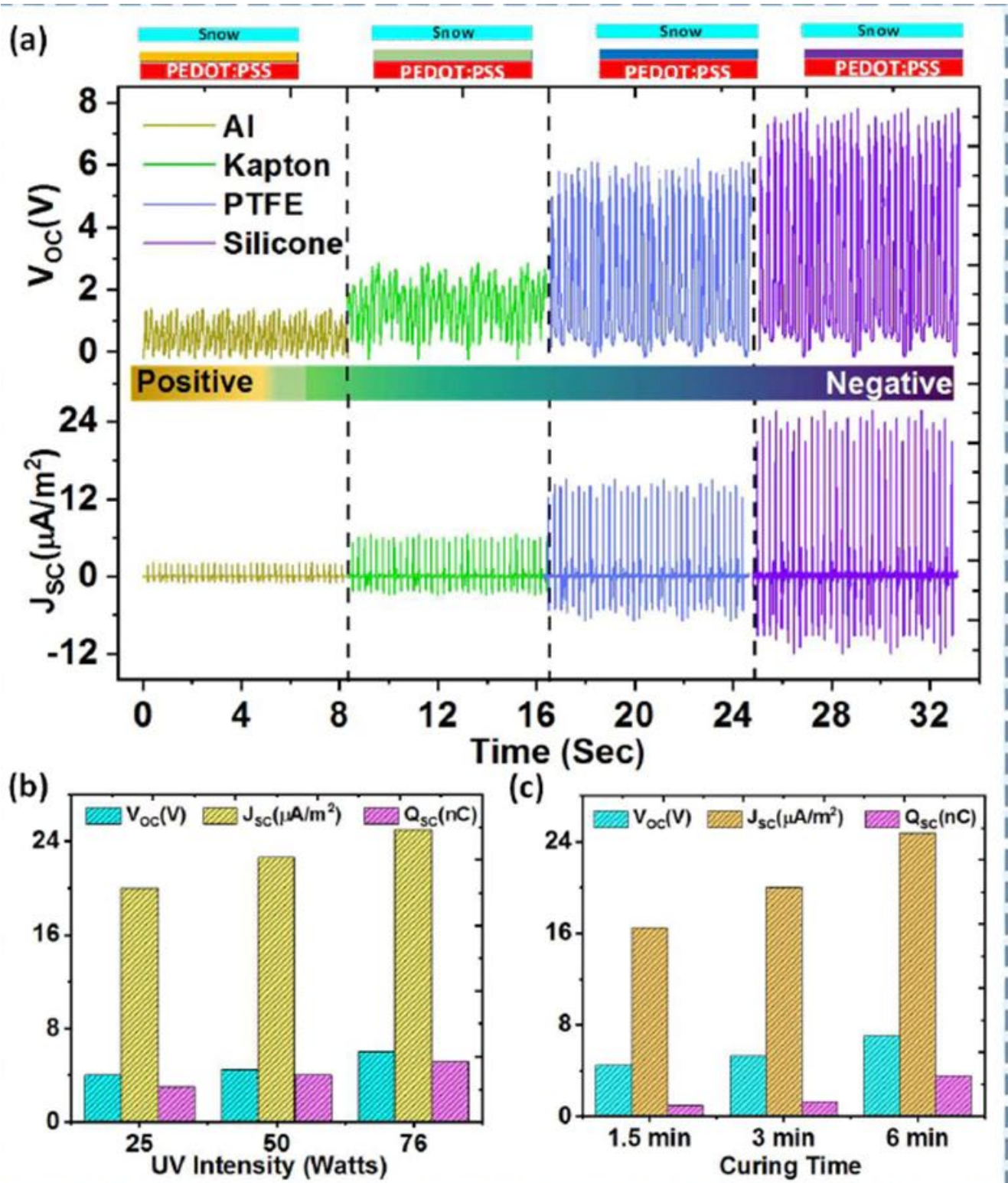
3. Evaluation of the electrical performance of a snow-TENG for harvesting energy from falling snow: Voc and Jsc define the triboelectrification performance of a snow-TENG using different positive and negative triboelectric materials (a); influence of the UV light intensity and curing time of the triboelectrification layer (silicone) on the electrical output of the device (b, c). The plots compare the open-circuit voltage, short-circuit current, and short-circuit charge under different conditions. (Source: UCLA)
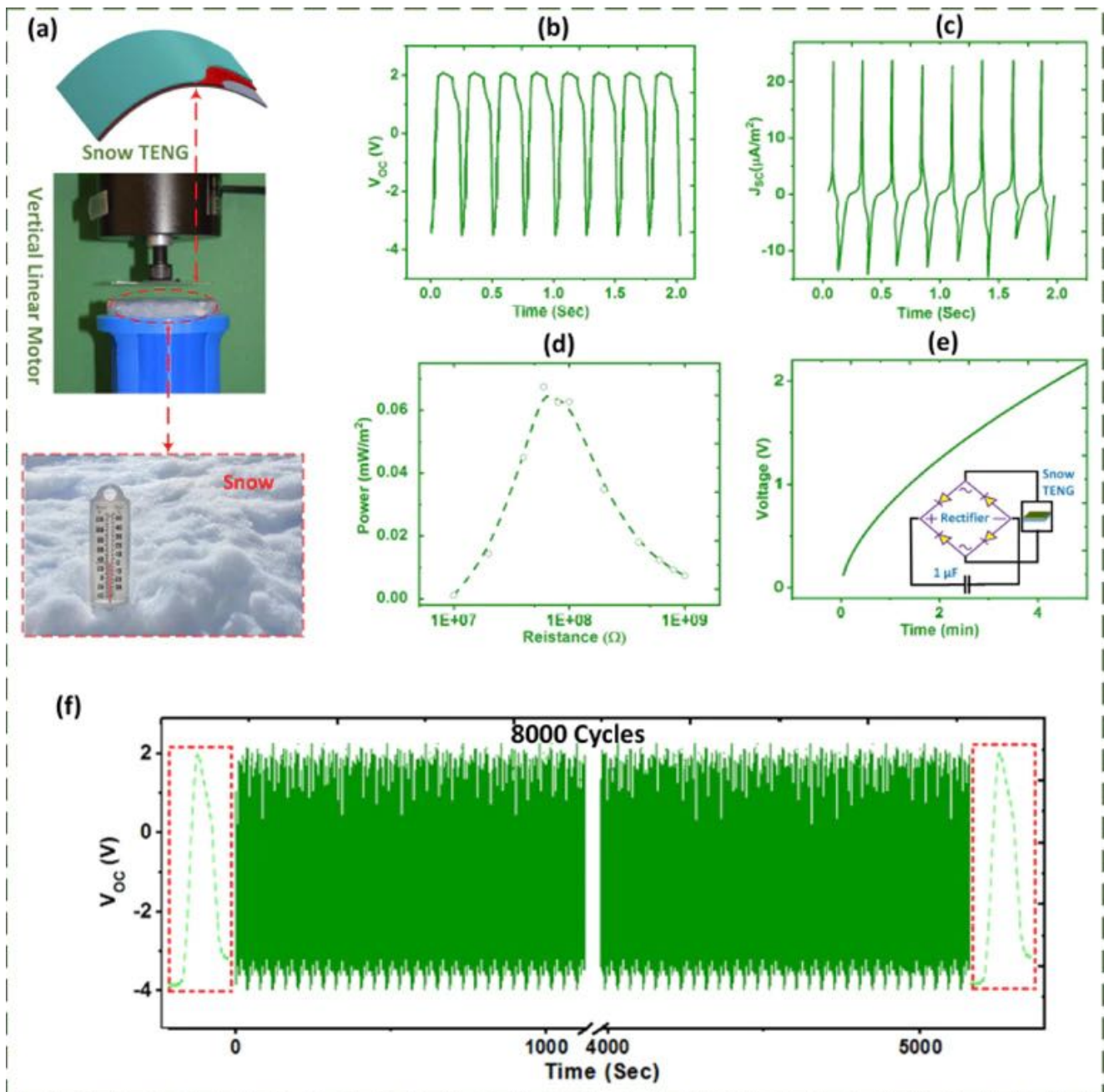
4. Characterization of the electrical properties of a snow-TENG in tapping and sliding scenarios: The testing setup showing a vertical linear motor, snow layer, and the fabricated snow-TENG (a). Open-circuit voltage, Voc; short-circuit current Jsc; and external load dependent peak power in the tapping scenario (b, c, and d, respectively). The charging behavior of a 1-µF capacitor using the output from the snow-TENG; results show that the capacitor can charge to 2 V in almost four minutes (e). There's no apparent degradation in voltage profiles for the snow-TENG even after about 8000 cycles of repeated loading and unloading at 3-Hz rate (f). This confirms that the snow-TENG is a durable and stable device, even with long-term usage. (Source: UCLA)

The team did more than merely build an energy-harvesting transducer and power source. The snow-TENG can function as a self-powered sensor and weather station to monitor the weather in real time to provide accurate information about the snowfall rate, snow accumulation depth, wind direction, and speed in snowy and/or icy environments. In addition, it can be used as a wearable power source and biomechanical sensor to detect human body motions.

The team believes the device could be produced at low cost given "the ease of fabrication and the availability of silicone," added the project leader Richard Kaner, professor of chemistry and biochemistry, as well as materials science and engineering, and who holds UCLA's Dr. Myung Ki Hong Endowed Chair in Materials Innovation.

Full details of theory, fabrication, and test are in their paper "All printable snow-based triboelectric nanogenerator" published in Elsevier's *Nano Energy*.

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