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TECHNOLOGY

How smart windows save energy

Specialized glass that keeps heat in during winter and lets it out during summer could make buildings much more efficient — if costs and complexities don't get in the way

By Brittney J. Miller | 06.08.2022

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The natural light that streams through a sunny window is great — until you're squinting and wiping sweat off your brow. You can shut the shades or turn on the air conditioning, but you're left with a dark room or a rising electric bill.

A solution to this conundrum was thought up 40 years ago: smart windows, tunable to your preferences. By using special materials that block specific wavelengths of light, these windows adapt to the weather or to your personal comfort. Too hot? The windows can become tinted to block light and keep rooms cooler. Too cold? The tint disappears, letting warm natural light heat your space. Want some privacy? Some glass can cloud at the flick of a switch.

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Over the past few decades, advancements in smart window research have moved the tech well beyond the lab: The market for smart glass is expected to reach $7.5 billion by 2028. Types of smart windows can already be found in boats, cars and airplanes and are making their way into buildings such as offices and airport terminals. And, assuming they overcome a few key challenges, they could play an important role in making homes more energy efficient one day, proponents say.

Buildings account for a whopping 39 percent of energy consumption in the US, and 35 percent of that is associated with heating, ventilation and air conditioning. Because smart windows can selectively block heat or let it in, they can bring down these energy needs: Roughly 35 percent of a typical building's energy is lost through windows.

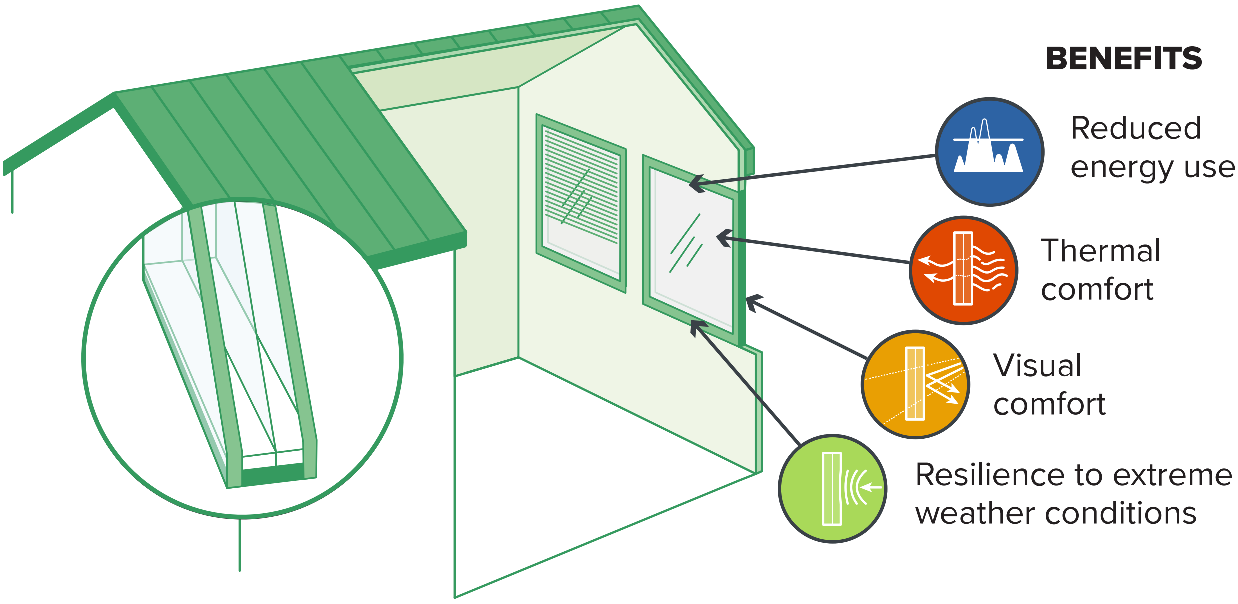
But for smart windows to go mainstream — and trim everyone's energy use — the price needs to go down. Current devices can cost up to 10 times the price of standard energy-efficient windows. Making the tech cheaper, and maybe even smarter, are areas of keen interest for researchers.

In the future, says materials physicist Claes-Göran Granqvist, “there's no reason really to have any other windows than these smart windows.”

Like a battery

Smart windows originated long before phones and televisions were considered “smart.” In the early 1980s, scientists from Chalmers University of Technology in Sweden and the Lawrence Berkeley National Laboratory in California were brainstorming new ways of making energy-efficient building materials. The researchers came up with the idea for a responsive window that would dynamically change its tint. Granqvist, who was part of that early research, employed the phrase “smart windows” on a grant application. The name stuck — and the first smart window came to fruition in 1984.

The many roles of modern windows



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Windows help create enjoyable spaces within buildings and play important roles in maintaining a comfortable indoor environment. Next-generation smart windows will be key to a greener, more energy-efficient economy.

The original prototypes spanned mere centimeters and featured glass that reversibly changed from transparent to darkened, a feat accomplished by sandwiching together glass, several layers of materials and transparent conductors that supplied small jolts of electricity. The voltage altered how the materials interacted with light — changing the wavelengths that were reflected or absorbed.

As the tech advanced, researchers explored other substances that manipulate light in response to other prompts, such as heat, ultraviolet light and magnetism. Today, a range of special "smart materials" is used, and researchers continue to investigate new ones.

Those early prototypes used "electrochromic" materials, meaning they reversibly change in response to electrical current or voltage. Electrochromic windows typically feature five layers overall, including two layers that serve as electrodes (like the positive and negative poles of a battery) and an inner electrolyte layer that contains ions. When voltage is applied, positively charged ions are driven into one layer while electrons move into the other. The reaction creates a tint that blocks some visible light as well as the heat-packed infrared light. The tint remains until another round of voltage triggers a reverse reaction that extracts the electrons and ions, thus turning the window transparent once again.

“It’s just like in an electrical battery,” says Granqvist, of the Ångström Laboratory of Uppsala University in Sweden. “You have to put in some energy to charge it, but then you can keep it for a long time.”

Electrochromic glass is widely used in smart windows, and can already be found in privacy screens, display panels, boat windows, aircraft windows and some car sunroofs. Some types of electrochromic glass are nearly opaque when they aren’t powered. In this state, the glass’s responsive materials, whether crystal droplets or other suspended particles, are arranged haphazardly, scattering light instead of letting it pass through, making the glass cloudy. But zap it with an electric current and the droplets or crystals line up — turning the glass transparent.

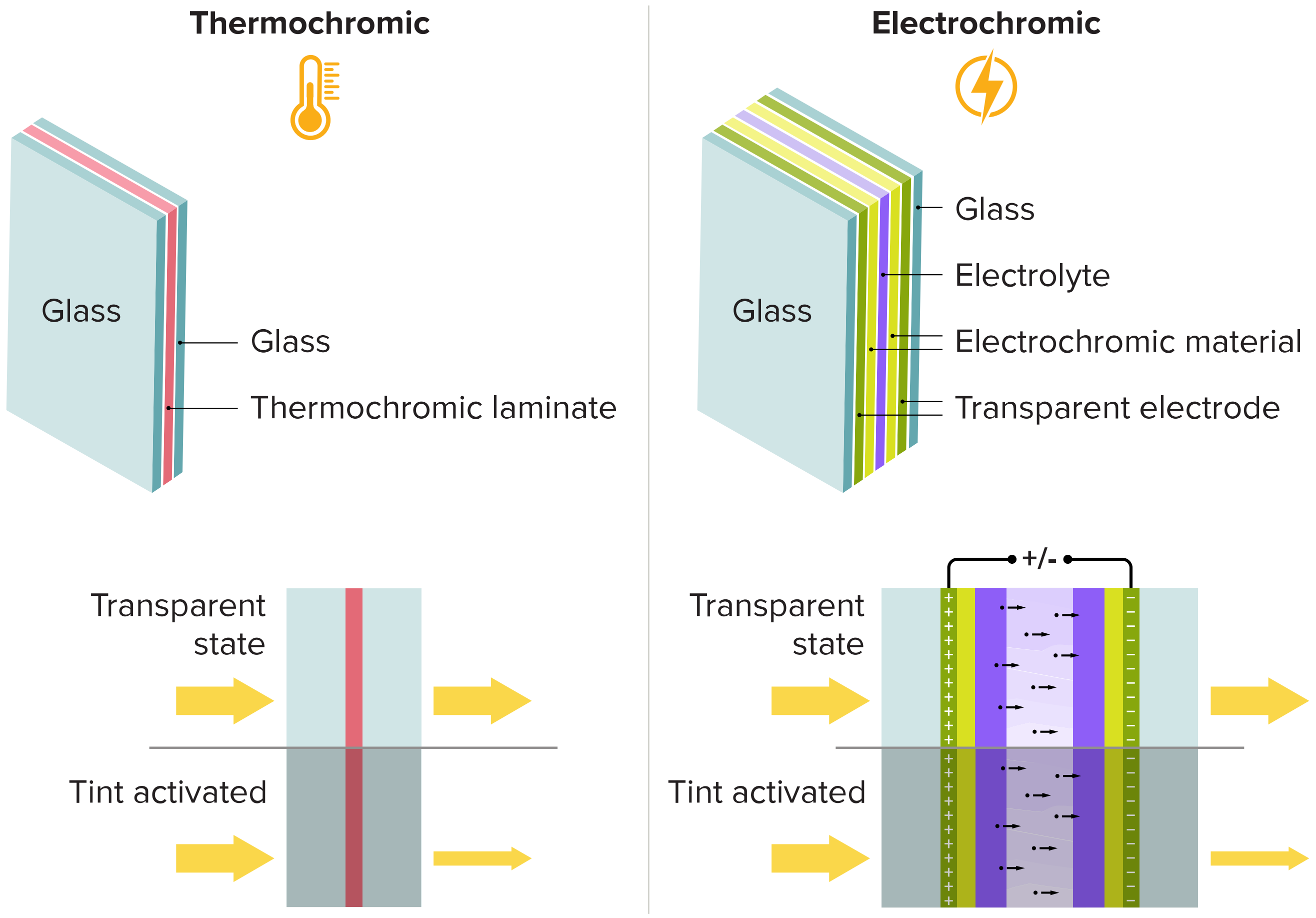
These and other electrochromic windows give building occupants manual control over tint levels, but electricians are required to properly build the electrode arrays and accompanying wires, complicating design and installation. This drives prices much higher than some other smart window designs. On the other hand, the materials are relatively cheap, and inexpensive and scalable production methods are on the horizon, Granqvist says.

And electrochromic windows still have room to improve. Researchers continue to investigate new responsive materials, with the aim of upping efficiency and window longevity. For example, a prototype containing tin oxide doped with two other metals that block both infrared and visible light lasted for many more on/off cycles than many existing electrochromic windows, scientists recently reported in *ACS Omega*.

Heat responsive

Another class of smart windows that change in response to heat, called thermochromic, doesn’t have the complicated wiring or power supplies of electrochromic windows. One thermochromic material that’s long been studied is vanadium dioxide (VO_2), says materials scientist Harlan Byker, who founded the company Pleotint, a maker of dynamic window glass.

Two types of smart windows



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Smart windows can switch between a transparent state and blocking state, a feat achieved by taking advantage of materials that reversibly shape-shift. Some materials alter in response to heat or electricity (shown); others respond to a magnetic field, mechanical strain or humidity levels.

VO_2 has the ability to shape-shift at higher temperatures (about 68 degrees Celsius, or 154 degrees Fahrenheit), increasing its ability to reflect infrared light. This allows visible light to continue to stream in, brightening the room, while lowering the amount of incoming heat, keeping the room cooler. Researchers can mix special substances into VO_2 to make it reflect at lower temperatures, but this hinders its reflection of light — making it difficult for the product to transition from the lab to commercial markets, Byker says.

Next-generation thermochromic windows may use different materials that absorb light instead of reflecting it, creating a continuous tint as temperatures rise, similar to electrochromic windows. One recently developed substance harnesses interactions between metal ions and other molecules to absorb less infrared and visible light when it's cold outside, thus allowing more heat in. When it's hotter, the materials absorb more light, keeping its associated heat out.

Each temperature-responsive material transitions at different temperatures and can look more or less tinted — and has challenges, says materials scientist Long Yi of the Nanyang Technological University in Singapore. Some, such as a polymer called hydrogel, are great at deflecting heat but feature a tint too opaque to see through. Others, such as VO_2, are transparent enough to conserve views but aren't as energy efficient because they can't reflect heat as well.

"There's no perfect materials," Yi says. "We can only find the perfect material for certain applications."

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One application is to engineer windows that not only scatter light but also trap its heat. Yi's lab, for instance, is developing thermochromic windows that can store heat collected at the sunniest part of the day and release it when demand and costs are lower during cooler parts of the day.

They can do this by placing hydroliquid — a combination of water and hydrogel — between two panes of glass. Chains of polymers inside the hydrogel expand when temperatures dip under 30 degrees Celsius (86 degrees Fahrenheit), turning the glass transparent. Above this threshold, the chains crumple like paper and entangle with each other to create a tint, scattering near-infrared and visible light. Thanks to the water in the mixture, which can hold high amounts of heat, hydroliquid absorbs the warmth, gradually releasing it over time. This can reduce heating, ventilation and air conditioning energy needs by 35 percent compared to double-pane glass, according to Yi's simulation data.

Her latest study introduces a two-way window. Described in 2021 in *Science,* Yi's team created a window — featuring energy-efficient coatings and VO_2 — that blocks heat-packed infrared light from entering buildings while letting indoor heat radiate out, thus cooling rooms in the summer. This mechanism reverses in the winter as temperatures grow colder — the materials let light enter and prevent indoor heat from radiating out. Compared with current commercial, energy-efficient glass coatings, this new tech could save up to 15 percent in energy consumption, Yi says.

How smart windows save energy

Researchers are developing smart windows that block the entry of heat-packed near-infrared light in summer while allowing heat to radiate out (left); in winter these windows let the near-infrared light in and keep indoor heat from radiating out (right). Visible light comes through in all seasons.

CREDIT: S. WANG *ET AL / SCIENCE* 2021

Growing panes

Smart windows can help the world make strides in energy savings — but, as seen with other innovations like electric cars, the road to a greener future can get a bit bumpy.

The steep price tags on smart windows are major obstacles to their expansion into more spaces, notes a 2016 overview of smart window materials in the *Annual Review of Chemical and Biomolecular Engineering*. Electrochromic windows, for instance, can be several times more expensive than energy-efficient windows because of their complicated powering systems and lengthy installation processes. And though thermochromic windows are cheaper, they still cost more than regular windows. Most consumers would rather pick the cheaper option, even if they lack the energy benefits of smart windows.

Scientists continue to improve the tech, but at this point the success or failure of smart windows depends largely on the economics. For smart windows to take off, their prices need to decrease, says materials scientist and electrical engineer Carl Lampert, a managing partner of the window coatings consulting firm Star Science. Including the windows in government rebate programs — like the Energy Star symbol for energy-efficient products — could help. Better educating consumers on emerging advances, their performance and energy savings could also raise demand.

Research is slowly paving the way toward simpler, cheaper and more durable smart windows that cut down costs and risks. But consumers may have to wait for them: Yi estimates that it may be 10 years until new products leave the labs and enter the markets.

Eventually, such windows may be more widespread, passively adjusting to consumers' desires or responding to the press of a button — like a television's remote control, Lampert says. He imagines a future where he can ask for a smart window at Home Depot without causing confusion among the workers. And other researchers agree:

"Dynamic windows are inevitable," Byker says. "It's just a lot of birthing pains here."

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