in the smooth operation of the house, the building has redundant systems such as geothermal heating and cooling equipment in the basement and solar thermal heating apparatus on the roof. Malkawi's aim is to use neither, if possible. Failing that, the fallback (for example, in winter) will be solar thermal heat; geothermal is a distant third option.

The main research questions, he adds, have nothing do with the specific energy-generation technologies used, because those change and "can be put on and off like a jacket." He wants to know whether an algorithmically controlled building can optimize itself. How would complex building data be used to develop such algorithms? What is the minimum number of sensors needed? And can this approach be deployed at scale?

It's machine learning for houses: sensors connect to a "brain" that constantly optimizes the environment.

"We are a research institution," says Malkawi. In analyzing all the data from HouseZero, "The main goal is to generate knowledge and understand what people don't have the capacity to understand now." There are many complexities in understanding building-performance behavior. One of the hardest computational tasks will be adapting to the building's human occupants. "The variables and uncertainties of people's behavior," he says, "are really one of the most complicated things!"

For more information on the CGBC, see **harvardmag.com/cgbc-14.**

~JONATHAN SHAW

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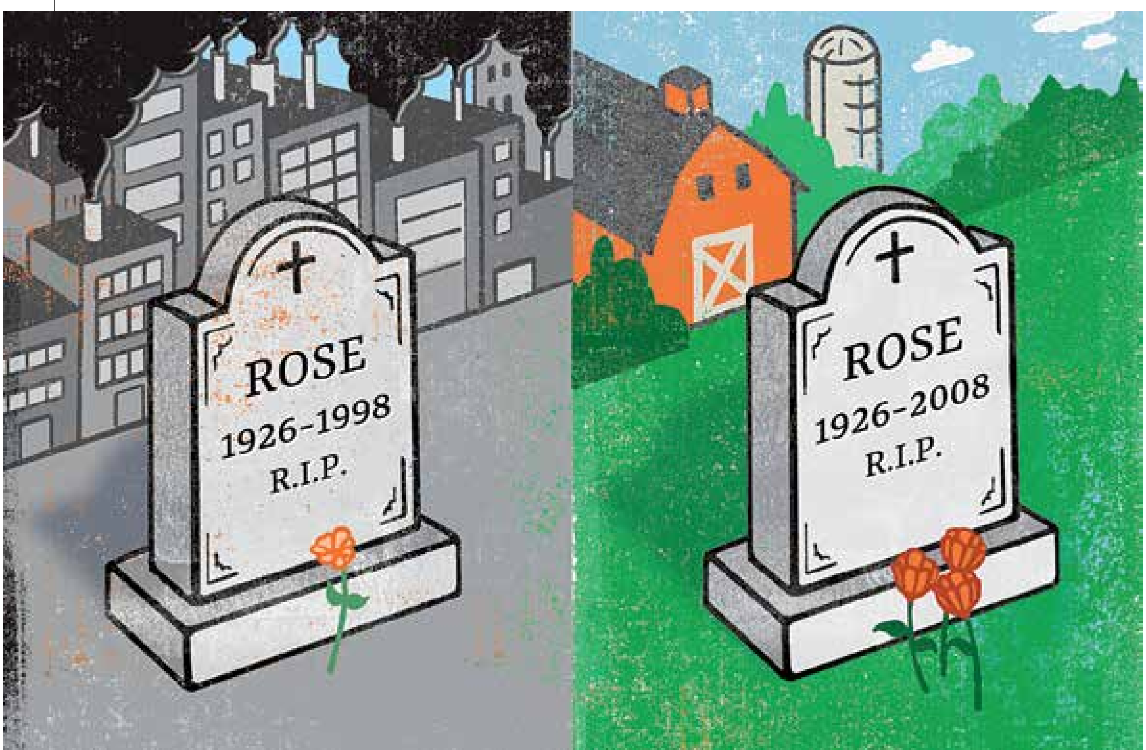
ECHOING EVIDENCE

A Particulate Problem

TWENTY-FIVE years ago, a team of eight University researchers famously estimated the critical impact of air pollution on mortality rates across six American cities—findings that came to be known as the Harvard Six Cities Study. Because the researchers were steadfast in keeping confidential the personal health data of the 8,111 Americans who participated in the study, and the findings would prove costly to the operators of fossil-fuel-burning power plants, the work faced aggressive scrutiny from Congress as well as the Environmental Protection Agency (EPA), on the grounds that it used so-called secret science in seeking to influence regulatory decisions. The eventual regulations, based on the study, helped decrease harmful concentrations of fine-particulate matter (particles smaller than 2.5 microns wide, a main source of which is fossil-fuel combustion) in the nation's air, thereby improving public health.

Last June, eight new Harvard-affiliated researchers revisited the study, using new technologies and innovations in statistical analysis and examining Medicare data—the largest and most public dataset available documenting the health of U.S. citizens—thus presumably averting renewed charges of secret science (an issue raised anew by current EPA administrator Scott Pruitt). Their findings breathe new life into the main conclusion of the original Six Cities research: that fine-particulate matter, even in concentrations *below* the current national standards, drives up mortality rates across the country.



Professor of biostatistics Francesca Dominici is one of the 2017 study's lead researchers. The co-director of Harvard's Data Science Initiative explains that quantifying the effects of particulate pollution at levels below national standards poses a unique challenge, comparable to "walking into a clean kitchen and trying to find…the dirty spots that you need to clean. As we try to study lower and lower levels of fine-particulate matter…it becomes increasingly difficult" to find the dirt. But Dominici and her colleagues had time

Illustration by Blair Kelly

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and technology on their side. To calculate the impact of fine-particulate pollution on public health in the United States, they used massive amounts of data not readily accessible in the early 1990s, including NASA satellite data from rural areas where pollution tends to be lower than in large cities. The team also relied on innovations in artificial intelligence and predictive modeling to simulate the effects of air pollution in different regions.

One of the most important differences between the original 1993 study and Dominici's research lies in the improved methodology of the statistical analysis, which is her area of expertise. To illustrate, she invokes the hypothetical profile of a woman named Rose who lives in an Ohio town where the air is highly polluted. Rose has cardiovascular disease and struggles with obesity; she eventually dies at the age of 72. Thanks to better data in greater quantities, researchers are able to find a matching demographic profile: another obese, 72-year-old woman with cardiovascular disease, but in this case, living in a low-pollutant town in Oregon. Because the two women breathe different levels of fine-particulate matter, researchers are able to infer its respective role in each woman's death.

Better data-matching also enabled the researchers to determine that even when air pollution levels are below national standards, self-identified racial minorities and low-income Americans are disproportionately affected. This proved true even after controlling for many other interrelated factors at issue for these groups, including limited access to medical care and poorer health overall. "Matching is the best way to control variables," Dominici emphasizes. "It's never going to be perfect, but we're getting as close as we possibly can with today's computing resources."

Dominici has no expectation of immediate regulatory change. The EPA has a well-defined process through which it examines epidemiological evidence every few years to determine if national air-pollution standards need to be lowered, and the next evaluation is at least a year away. In the meantime, she hopes her team's findings will inform Americans that "fossil-fuel combustion is playing a key role in air pollution. Air pollution is driving a public-health problem that is happening right now, for this generation."

~OSET BABÜR

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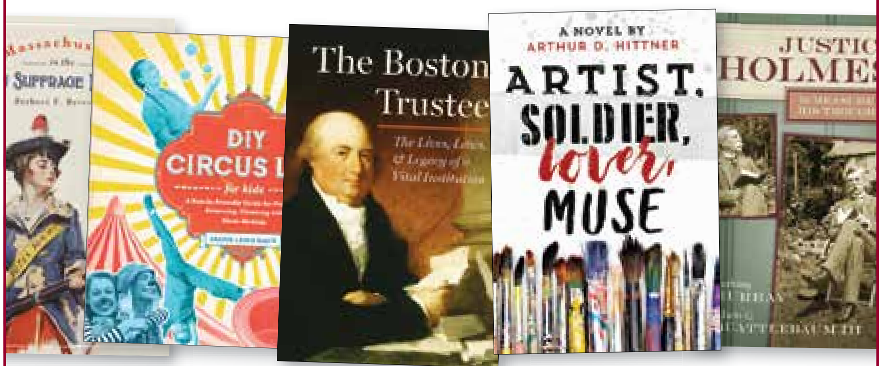

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