Yale

SUSTAINABILITY

Inside/Outside

Environmental engineers Jordan Peccia and Drew Gentner are finding new ways to study the air we breathe — both indoors and out

Alexa Bakker, a doctoral student in Jordan Peccia's lab, takes samples from an air conditioning unit at Yale's West Campus.

Humans have long taken to the indoors in one fashion or another. Ice age humans lived in caves, or they made tents from the skins and bones of mammoths. By 8000 B.C. Mesopotamians were making houses from mud-brick, and our living situations became increasingly sophisticated from there. It makes sense. Outside can be cold or rainy, critters crawl all around, and you need a place to keep your stuff.

But there's a catch: the more your living quarters separate you from the outdoors, the more you're courting an unhealthy living situation.

"Humans evolved to live outside and not inside, and the organisms inside are very different from the organisms outside," said Jordan Peccia, professor of chemical & environmental engineering. "But with lots of ventilation, you can make your inside look like outside. That's seems counterintuitive to what buildings are for — they're supposed to protect us from the outside, but really, we need a lot more of what's outside."

Research shows that buildings with high ventilations correlate with better health than low-ventilation spaces, which are associated with higher incidences of dust mites and carbon monoxide. Ventilation is one of the focuses of an ongoing collaboration between Peccia's lab and researchers from the University of Tulsa, which is looking at about 100 homes and schools in Cherokee Nation, one of the largest Native American tribes in the United States.

"Cherokee Nation has a 19 percent asthma rate among children, compared to the U.S. population in general, which is 5 to 7 percent — so it's very high," Peccia said. "There are times of the year when there are so many respiratory diseases that they close schools because everyone has the flu. So it's pretty clear that there's exposure to microorganisms at the schools and at the homes."

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In the participating homes and schools, the researchers will look at air flow and how residents' cleaning methods affect the travel and settling of dust. After collecting samples from surfaces in different rooms and from the air inside and outside the homes, the researchers will also analyze the exchange rates of the ventilation in the homes. Once that part of the project is complete, they will take more measurements to determine whether better ventilation affects microbial communities — that is, whether it changes the concentrations of allergens, bacteria, and fungi.

Sarah Kwan, a doctoral student in Peccia's lab, is leading the study for Yale.

"We can't cure asthma or allergies in children who already have it," she said, "but we're looking at how we can change the indoor environments to lessen the number of bad episodes they have, decrease the absenteeism at their schools and have fewer days in the hospital due to their indoor environments."

Rates of asthma and severe allergies for the general population of Colorado are similar to those in the rest of the U.S. Poverty plays a big role in why the rates are so high among the Cherokee Nation population. The roofs, walls and windows in these homes are often compromised in a way that results in moisture damage and bad ventilation — all things that contribute to increased microbial exposures.

Compounding matters, indoor air quality resources are scarce in the Cherokee Nation. It's an unfortunate situation, but makes the Cherokee Nation volunteers an ideal group for the study. "If you can start with the most sensitive group and you can help them, then hopefully you can help anyone else suffering from it using the same changes," Kwan said.

The homeowners in the study will receive cleaning supplies and instructions on proper cleaning methods. After a few months, more samples will be collected, and the researchers will determine if the new cleaning equipment and methods had any impact.

"The idea is to understand what's going on in their homes," Peccia said. "We know a lot of these microorganisms are the ones that cause severity of asthma. We want to understand how some really modifiable parameters of a person's home can affect their exposure to these microorganisms."

Since the participants in the study are mostly families with low-incomes, the researchers need to come up with inexpensive remedies. Kwan said she expects their suggested solutions will buck current trends in architecture, which is to reduce the air exchange in buildings. This helps keep down energy costs, but Kwan and Peccia say it could also have health costs.

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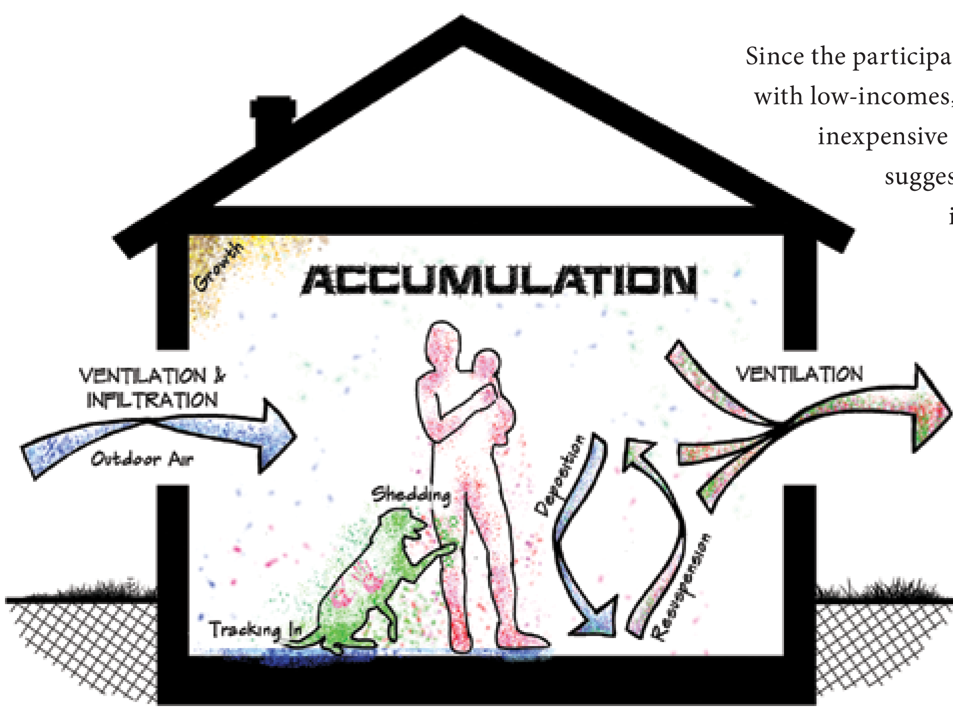

Sources and physical processes that govern the assembly of indoor microbial communities.

Researchers take samples in an effort to shed light on the unusually high asthma rate of children in the Cherokee Nation.

Peccia suspects that the high proportion of illness of people who live and work in air conditioned buildings is directly related to microbes.

"The indoors can become concentrated environments and incubators for everything that you bring inside, and if they're closed up, there's no way for this stuff to get back out," she said. "We're trying to show that if you have a higher exchange rate, and let the outdoors flush out the indoors, then maybe we can reduce some of these health effects."

You don't have to travel far to happen upon the hazards of indoor living, as another project out of Peccia's lab shows. Although it has long made sweltering summer days bearable, air conditioning could also be making you sick. Studies have shown that there's a high proportion of illness among people who work and live in buildings with air conditioning. Not majorly sick, but some tightening of the chest, some dry coughs and other symptoms.

Researchers don't know why this is, but Peccia suspects it has something to do with microbes. "We don't know what or how, but it seems that when you take the microbes away from the air conditioning system, people feel better," Peccia said. His lab has received a grant from the Sloane Foundation to take a deeper look into the unseen world of the air conditioner, and what it might be doing to its users. He believes air conditioning units are creating unique environments conducive to only certain types of organisms.

"When you think about it, they're wet, kind of cold places but they go through cycles of wet and dry. There's stuff in there and that gets distributed throughout the building," he said. "We're going to dig through the coils of these big systems and we're going to try to see what grows there — what kind of fungi, what kind of bacteria are growing on these coils."

Using genetic methods, they'll take an inventory of all the microorganisms they find in the units. Then they'll measure the rate at which these microorganisms are distributed into the air.

For Peccia, it's one more project that keeps him inside, searching for new ways to improve our indoor life.

"This wasn't my idea of what I'd be doing when I went into environmental engineering," Peccia said. "I thought I'd be walking fields and testing water. But we spend 90 percent of our time in buildings. This is our environment, whether we like it or not."

Of course, the air outside isn't perfect either, and in some places, it's downright terrible. Getting a better handle on exactly what's in the air is an ongoing quest, and no easy task, considering that the atmosphere comprises a complex mixture of molecules with trace amounts of more than 10,000 organic compounds in the gas and particle phases. Drew Gentner, assistant professor of chemical & environmental engineering, is working to expand the range of measurement capabilities and couple them with new ways to analyze the data. By doing so, he hopes to get a clearer picture of what exactly is in the air to better get a sense of how to make it cleaner.

"In the past, the field has had several major instances where advancements in instrumentation have enabled research and a much more detailed understanding of the chemical composition and dynamics of air pollutants," Gentner said, while showing off some of the high-end instrumentation in his lab. Detecting the smallest of trace concentrations of chemicals in the atmosphere requires extremely sensitive instruments. Some of the machines operate at the level of femtograms (an order of magnitude below nanograms and micrograms — that is, very small).

Gentner said examining the air at this level of precision gives researchers in his field a new frontier to explore.

"It's almost the atmospheric equivalent of exploring the deep cosmos or the deep ocean because we're looking at a mix of compounds that are known, understudied and unknown," he said. As science has advanced in the last

Gentner displays an early prototype of his portable air sensor.

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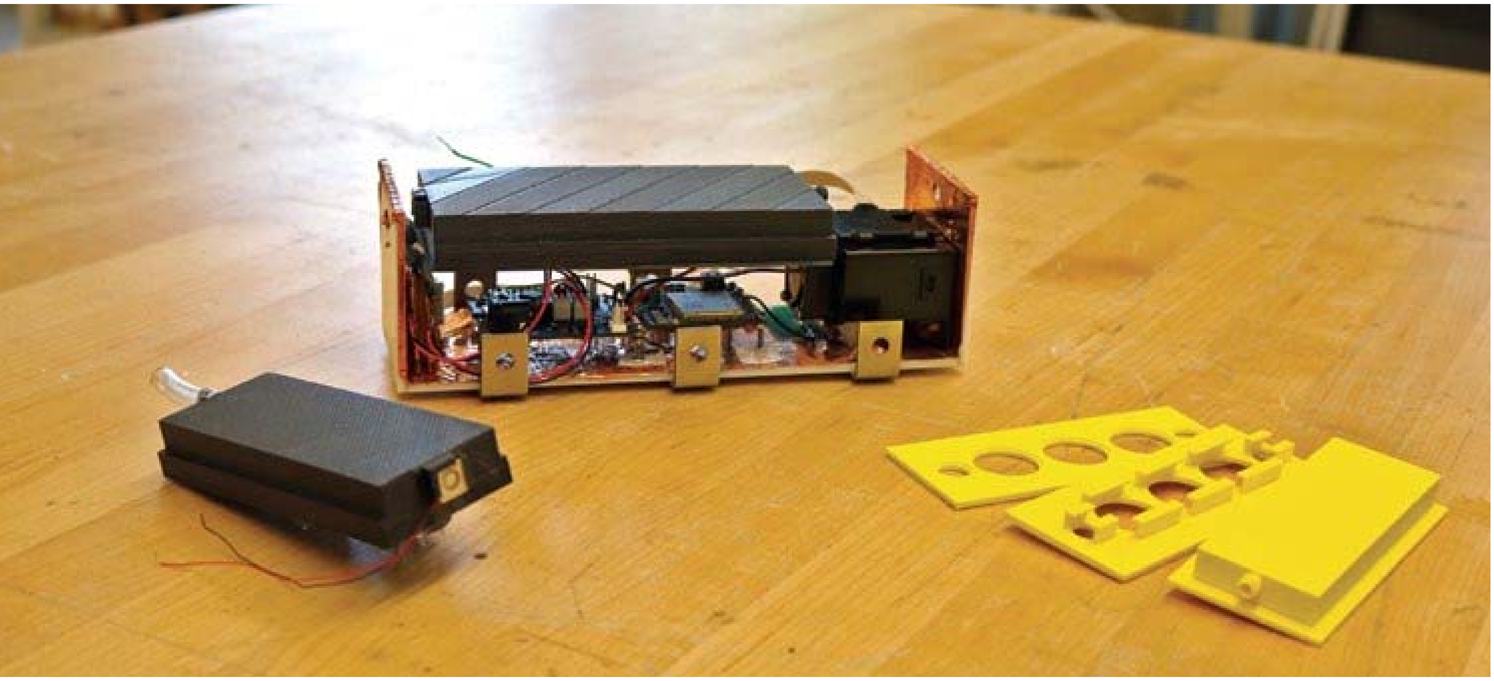


half-century or so, he said, the makeup of the atmosphere has proved to be remarkably complex, and "with every advance in instrumentation, we uncover new chemistry and a deeper understanding."

Getting to the next level of knowledge requires taking some novel approaches. In addition to his group's work with cutting edge analytical chemistry equipment, they have a project focused on spatial and temporal variability of air pollution. That means designing and building a new generation of low-cost, air quality monitoring devices. At the Center for Engineering Innovation & Design (CEID) this year, Gentner and his students have been working on portable devices that will be worn by volunteers in Baltimore as they go about their daily routines. For the same project, Gentner and the students are also making stationary sensors, each smaller than the size of a shoebox.

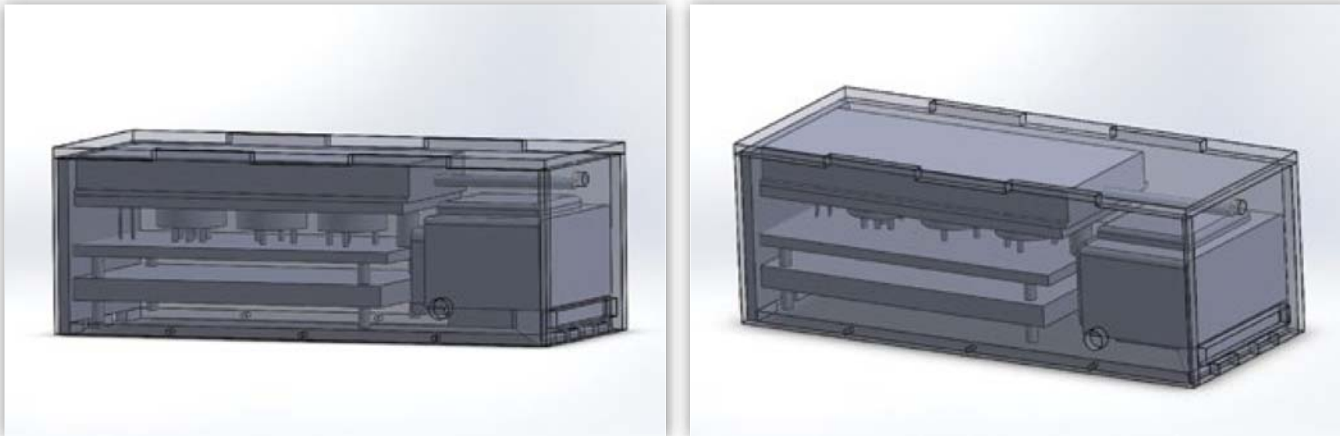
The effort is one of four core projects of the new Solutions for Energy, Air, Climate, and Health (SEARCH) Center, created with a five-year, $10 million grant from the U.S. Environmental Protection Agency (EPA) to study the relationships between air quality, energy policy, climate change, and public health. Michelle Bell, the Mary E. Pinchot Professor of Environmental Health at the Yale School of Forestry & Environmental Studies, serves as the director of the multidisciplinary research center. Johns Hopkins University and other institutions will serve as partners. It is one of only three centers funded by the EPA.

The high-resolution air pollution sensor networks and wearable sensors are being designed to give real-time data on common air pollutants. If all goes according to plan, the devices could help usher in a new generation of air quality studies.

Most cities have a handful of stationary field sites to monitor air quality. "Single-point measurements of air pollutants have historically been used to represent a whole region or city, and that's been a limitation for air quality studies," Gentner said, adding that "new opportunities abound as low-cost sensors become more accurate and precise." The stationary and portable monitors will make for some very detailed networks that will provide valuable information for studies on pollutants, how they are transported through the air and the level of human exposure to them.

Making the sensors small enough for volunteers to wear daily, and sophisticated enough to do everything Gentner wants, takes some work. Genevieve Fowler '16 was part of the first of two groups of students to work on the sensors. "It's been exciting to be working on something that could have such an impact," she said.

Fowler said the prototype they developed is a good start, but the second group of students (working on the sensors this semester) has its work cut out for them. With more design work ahead of them, Fowler said they will "have to



Facing Page: *One challenge for Gentner's lab is making the devices small enough to wear every day.* Above: *Early CAD renderings of Gentner's sensor.*

think about waterproofing and general durability for the housing. I think those are the biggest things."

The stationary sensors will be located in representative locations around the city: roads, schools and other places where people spend a lot of time. "With these networks, we'll have real-time measurements, 24 hours a day with fine spatial and temporal resolution on the air pollutants responsible for detrimental effects on human health and climate," Gentner said.

When the portable sensors are complete, the volunteers will wear the sensors at home and whenever they leave their home. One of the challenges is designing the sensor so users can carry the devices without even thinking about it.

The researchers chose Baltimore as the site for the sensors partly because of the proximity to SEARCH partner Johns Hopkins University. It also means that people from a wide range of backgrounds can take part in the study.

"It will allow us to look at a diverse group of people interacting with the built environment in different ways," Gentner said. "As part of the center, we're very interested in energy-related impacts — how do personal choices and regional-scale choices related to sustainability affect exposures to air pollution?"

Gentner said the portable sensors should be ready for use in 2017. They'll collect the data for two to three years and further analyses will look at how individual and broader policy choices affect air pollution and human exposure.

"This is a big effort going through the end of the decade and we're really excited about it," Gentner said. "These sensors have the potential to not only have an impact on this study, but also future studies with powerful methods for elucidating air quality."