AT ONE TIME, humans inhabited spaces only roughly protected from the elements, with very little separating inside from outside. It was only as we constructed more elaborate structures, covered dirt with flooring materials, and sealed openings with windows and doors, that we began to live and work in spaces that could differ considerably from the world outside.

Our eagerness to separate inside from outside has given us very comfortable surroundings, heated and cooled, closed off from outside air, clean and free of pests. But we now know that this sense of safety comes with a cost. Sealing buildings off to improve energy efficiency after the 1970s oil embargo led to cases of "sick building syndrome," in which building occupants fell ill from poor air quality.

Say the phrase "air pollution" and what comes to mind? Smog blanketed over city skylines? Smokestacks belching soot? Cars packed onto highways as exhaust shimmers overhead? Those scenes have become rarer over the past few decades as the U.S. has dramatically improved outdoor air quality, thanks to pressure from citizens and legislation like the Clean Air Act.

The same cannot be said for the air Americans breathe *indoors*. And that's a problem, since that's where most of us spend the vast majority of our time.

"Indoor concentrations of many pollutants can be higher than outdoors," says Joseph Allen, a public health researcher who spent several years in private industry investigating environmental problems in buildings, and now directs Harvard's Healthy Buildings Program.

The increase in indoor air pollution is in part an unfortunate side effect of well-meaning efforts to reduce energy use. It takes a lot of energy to bring in outside air and then heat or cool it, and so architects and engineers have made buildings more and more airtight over the past few decades, a trend that's only accelerated with the so-called green building movement. That's a good thing for the climate: Buildings are responsible for 40 percent of the energy used in the U.S., so reducing how much fuel they consume is a critical part of limiting greenhouse gas emissions.

But these buildings also have a problem: They don't really breathe. Indoor air can be filled with all sorts of gases and chemicals that can cause health problems, including carbon monoxide, ozone, particulates, volatile organic compounds (VOCs) like formaldehyde and benzene, and a variety of other chemicals emitted by indoor appliances and materials. At high enough concentrations, they can

irritate the eyes and lungs, cause headaches, exacerbate allergies and asthma, and potentially lead to longer-term illnesses, including cancer.

There is a growing recognition among building designers and public health officials that the effort to reduce the carbon footprint of buildings has sometimes overlooked the health of the people inside.

And even when buildings aren't actively making us sick, they may be failing to keep us healthy and productive. Poorly ventilated rooms accumulate pollutants as well as carbon dioxide, which humans exhale at every breath. Recent research has tied higher ventilation rates, which reduce levels of carbon dioxide, to better cognitive performance and reduced absences from illness.

"We need to make our buildings more energy efficient," says William Fisk, an indoor air quality scientist at the Lawrence Berkeley Laboratory, "but we need to do it in a way that protects our indoor environment."

Many indoor air experts now believe that better buildings — with improved ventilation, fewer indoor toxins and fresher air — can actually promote health. Studies increasingly link better air quality to clearer thinking and workplace productivity, which means that fresh air is better not just for workers' health but also for their bosses' bottom line.

OLD HOUSES AND BUILDINGS were terribly expensive to heat and cool, but they did one thing very well: Leak air. In drafty older homes, indoor air gets swapped with outdoor air roughly every hour; since the 1980s, this exchange rate has dropped by half, and in some well- sealed newer buildings, just 20 percent of the air is exchanged every hour.

The result? Reports of a phenomenon dubbed "sick building syndrome," where occupants reported a collection of symptoms including headaches, nausea and fatigue. These were eventually linked to the buildup of pollutants inside the buildings, in part because of lower ventilation levels. The ventilation standard was eventually raised back up a bit, but indoor air experts say that the new minimum still isn't enough.

What's so bad about stale air? The exact effects of poorly ventilated buildings are hard to pin down, as it's challenging to tie health effects to specific causes in the

environment. But research has landed on several potential threats.

In homes, unvented gas stoves, woodstoves and fireplaces are a major source of harmful particles and nitrogen dioxide, which can cause respiratory disease, and carbon monoxide, which interferes with oxygen intake. Mold, bacteria, pollen, pet dander and dust can build up and trigger allergic reactions.

Chemcials and Products pollute our air

And then there's the many chemicals in building materials, furniture, paint, flame retardants, stain repellents and personal care products that can seep out for many years after manufacturing. Known as volatile organic compounds, or VOCs, these chemicals have varying effects. Some are known carcinogens and some can be toxic at high levels. The effects of day-to- day exposures at lower levels are not yet understood. Organic solvents from household products like cleaners, cosmetics and paints are often two to five times higher inside homes than outside, according to EPA studies, and in offices, printers and copiers are fonts of VOCs. Formaldehyde, a VOC found in some pressed wood products, glues and textiles, is a known carcinogen and can trigger asthma attacks.

Hundreds of other chemicals in personal care products and perfumes, plastic products, flame retardants, and stain-resistant coatings are of potential concern to scientists, because some of them have been found to affect reproduction, hormones, or other aspects of health in animal toxicology studies.

Finally, there's the paradoxical case of carbon dioxide, a normal part of the air we breathe that was thought to be harmless except at extremely high concentrations. Carbon dioxide is used as a proxy for ventilation by engineers, because it builds up in occupied rooms if there's not enough air flow to dilute it.

But now researchers are learning that carbon dioxide is more than a benign way to measure air exchange rates: It may cause its own problems. A 2012 study led by Fisk at the Berkeley Lab found that people sitting in a room with moderately high carbon dioxide levels performed worse on tests of decision-making performance. The levels they were exposed to (1,000 and 2,500 parts per million) are commonly found in buildings. Allen at Harvard also led research showing that people had 61 percent higher cognitive scores while in rooms with low VOCs, typical in green buildings, and 101 percent higher scores when exposed to low VOCs and lower carbon dioxide.

This isn’t just a problem for workplaces. Schools often have cramped rooms packed with children, and carbon dioxide levels can reach several thousand parts per million. Work from the Berkeley Lab found that many public elementary schools in California did not meet state ventilation standards, and that lower ventilation correlated with increased absences from illness.