Indoor air pollution

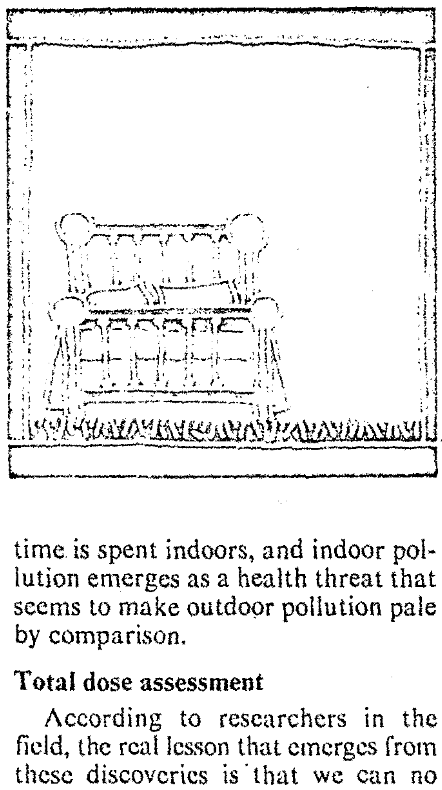
The discovery that pollutant concentrations are often higher indoors than out raises questions about energy conservation and casts into doubt much of the air pollution epidemiology done to date

One day last fall James L. Repace, an EPA employee in the Office of Policy Analysis, carried with him through his day's activities a portable monitor for respirable particles. He recorded the highest concentrations of the day not while walking in downtown Washington, nor while commuting during the rush hour, nor while driving behind a smoky diesel truck, but while cooking dinner that evening in his well-ventilated kitchen. The second highest levels were in the smoking section of the cafeteria at Goddard Space Flight Center, which he visited at lunchtime.

Repace's observations add just one more piece to a puzzle whose outline is already discernable: Indoor concentrations of pollutants often equal or exceed outdoor concentrations—and outdoor concentrations may have little to do with the true exposures to pollution we are all experiencing.

The high indoor particle concentrations Repace recorded are in no way flukes. NO_2, traced to gas combustion in stoves, has been found indoors at twice the outdoor level; CO in offices, garages, and hockey rinks is routinely in excess of the 8-h EPA standard; hydrocarbons from myriad sources appear in high concentrations; and radioactive radon gas, emitted naturally from a variety of building materials—and even by soil—has been detected indoors at levels that exceed ambient by factors of 2–20.

Add to this the fact that an estimated 90% of the average person's



time is spent indoors, and indoor pollution emerges as a health threat that seems to make outdoor pollution pale by comparison.

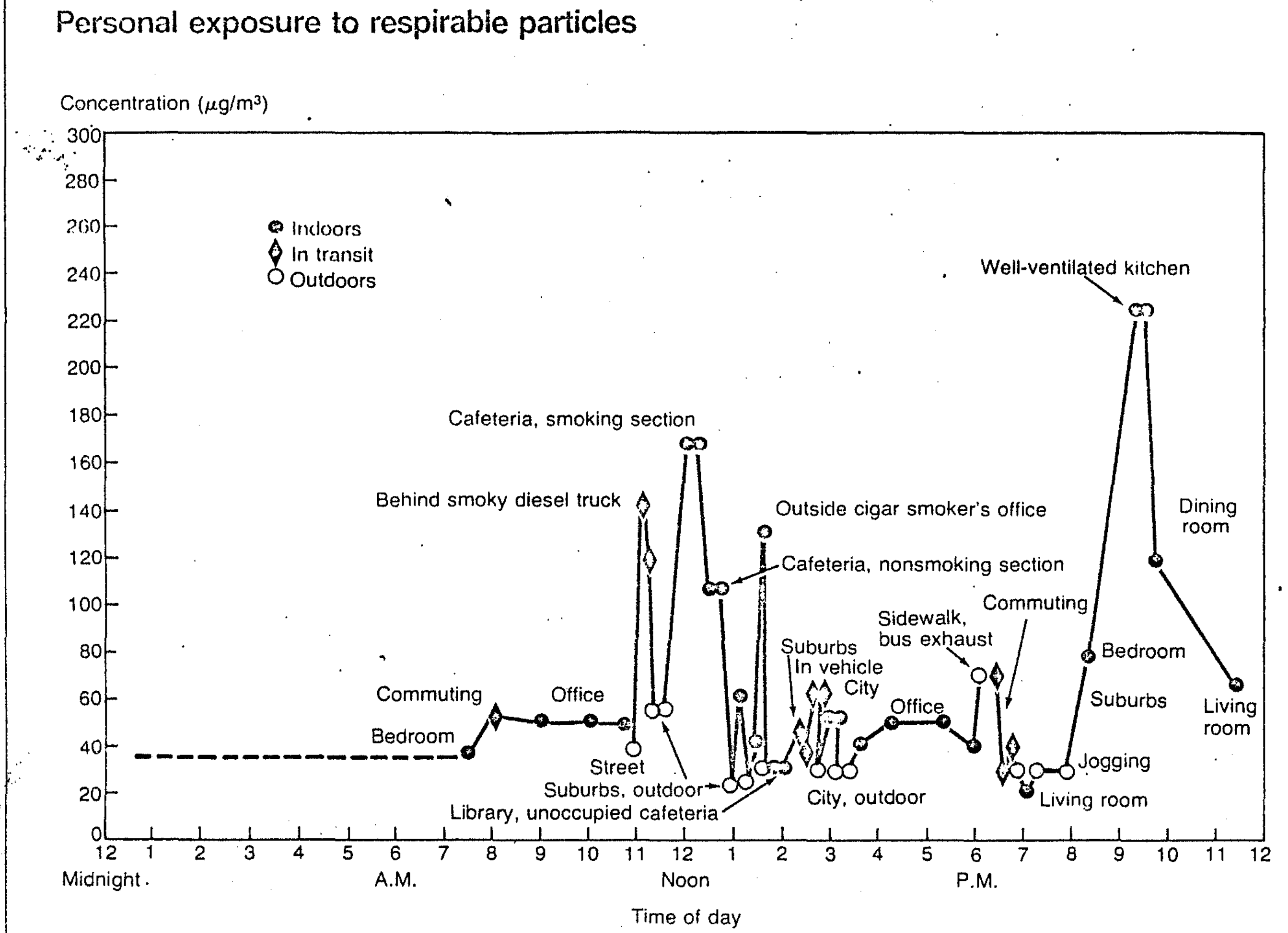
Total dose assessment

According to researchers in the field, the real lesson that emerges from these discoveries is that we can no longer use measurements from a single "microenvironment" as an indicator of the population's exposure to pollution. Ambient concentrations are an uncertain measure of personal exposure, and air quality standards framed in terms of ambient concentrations alone may be woefully inadequate to their mission of protecting public health. The key word, though, is "alone."

"The indoor environment is an entity by itself," said Demetrios Moschandreas of Geomet Technologies, Inc. (Gaithersburg, Md.), who has been involved in indoor air pollution studies since 1976. "But that does not mean ignore outdoor levels. We will miss the essence if we decide that we have spent all this money needlessly [on outdoor pollution] and now we have to spend twice as much on indoors. You have to consider the whole thing. That is why I go back to the total exposure concept—and total exposure is just that, total."

John D. Spengler of the Harvard University School of Public Health made a similar point: "The objective of our measurements is to find the exposure of the population to pollutants. The important thing about indoor pollutant measurements is sorting people out into exposure groups."

Determining when, where, and how exposure occurs is the key not only to limiting exposure, but even to understanding the fundamental effects of pollution correctly. Ultimately, Spengler said, "we're trying to get the right measure to associate with health effects." For example, is it long-term average, short-term average, or peak exposures that are most important? Where can fixed samplers be placed, and how many will be needed, to provide an accurate indication of personal exposure for a given segment of the population? And what are the key variables—such as use of gas stoves—that determine personal exposure? These are the questions that have been raised by recognition of in-



James L. Repace's exposure to respirable particles, as recorded by a portable monitor which he carried with him on Oct. 16, 1979.

door pollution, and that may be answered by further study of indoor pollution.

Shockers steal the show

But maintaining this perspective is difficult in the face of the undeniably disturbing revelations about indoor pollution. Some have been real horror stories.

In the course of a continuing epidemiological study involving six cities and some 20 000 subjects, Spengler conducted indoor and outdoor measurements in 73 houses. In those with gas cooking, NO_2 was measured repeatedly, and for as long as hours at a time, at over 500 $\mu g/m^3$. Annual mean values in kitchens with gas stoves may well exceed the ambient air standard of 100 $\mu g/m^3$. And the effects are noticeable.

"For nonoccupational groups, children for instance, you see two populations," Spengler explained. "The gas-cooking population is having a higher mean exposure than the electric-cooking population." And according to Spengler and others, that difference is associated with increased respiratory disease and decreased lung volume in the gas-cooking group.

Respirable particles can reach astounding concentrations indoors, particularly where there is smoking going on. Repace sampled particle levels in a variety of indoor environments and found consistently higher levels where there was smoking; typical values were 70–900 $\mu g/m^3$ of respirable particles in environments ranging from restaurants to church bingo games to a hospital waiting room. The grand prize went to an office building conference room, which tipped the scales at 2000 $\mu g/m^3$. The ambient standard calls for the 24-h average not to exceed 260 $\mu g/m^3$ more than once a year.

Formaldehyde has received much attention from the complaints of sickness, sometimes severe, that have followed on the installation of urea-formaldehyde foam insulation in houses. And according to Craig D. Hollowell of the Lawrence Berkeley Laboratory, "formaldehyde is just the tip of the iceberg of the issue of organics. We have found a large number of organic compounds" indoors, particularly in office buildings where carpeting, paneling, construction adhesives, and cleaning compounds contribute a whole grab bag of substances to the air.

Another shocker is benzo[a]pyrene. "BaP is elevated indoors and that is something that should concern people a great deal," said Moschandreas, who reported a concentration of 11.4 ng/m³ in one home which had a fireplace going. Wood-burning stoves and smoking can also jack up indoor levels of this "most unchallenged carcinogen," according to Moschandreas.

But the most frightening component of indoor air may be radioactive radon gas. Radon is emitted naturally by anything that contains radium-226—and that includes concrete, brick, stone, even the soil under building foundations. Radon decays to give rise to four "daughter" elements, all radioactive as well; these tend to stick to airborne particles which may then be inhaled. The dose of alpha radiation that the lung tissue receives when these inhaled daughters decay has been closely linked with lung cancer incidence in uranium miners exposed to high concentrations.

Hollowell's group has estimated that, at present, indoor exposure to radon daughters may account for as many as 1000–20 000 lung cancer deaths each year in the U.S.

Tightening up on energy—and air

Much of the attention that indoor air quality has received of late has arisen from concern over the effects of energy conservation measures, such as weather-stripping and caulking, that reduce ventilation rates. With a reduction in ventilation comes an increase in the indoor concentration of any pollutant with an indoor source. The two Department of Energy programs designed to cut building energy use—the Building Energy Performance Standards (BEPS) and the Residential Conservation Service (RCS)—have in particular forced the issue to a head.

But many researchers are quick to point out that the problem is not new. "The indoor environment was dirty before energy conservation came along," said Moschandreas. And Hollowell said, "Energy conservation programs have sensitized many people, but there was a problem even before you looked at energy conservation."

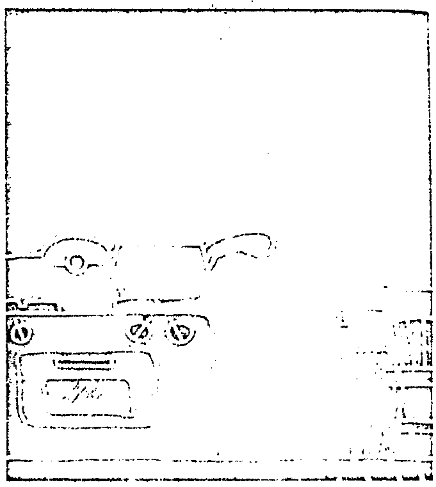
What *is* new is awareness of the problem, though in retrospect it is hard to understand how it could have taken so long to come about. Since about 1970 the EPA had been funding some work on indoor air quality, but at a very low level. "EPA looked at the problem as 'outdoor will determine indoor levels,'" said Moschandreas.

In 1976 the EPA sought proposals for a major study; the contract went to Moschandreas' group at Geomet; and, as Moschandreas put it, "they found out otherwise." Hollowell had meanwhile become interested in the indoor environment, in particular the role of emissions generated by gas combustion indoors. He pursued the matter with the Atomic Energy Commission, and subsequently with the Energy Department's building conservation section.

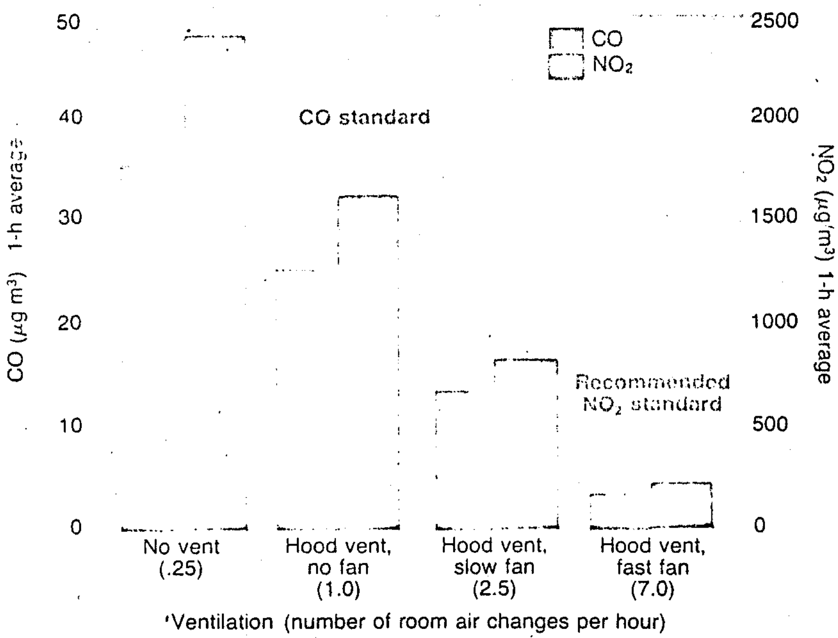
Energy conservation is what woke up the EPA policy people. When the DOE proposals were reviewed by the EPA last year, Repace "realized right away that both the RCS and the BEPS would have tremendous indoor air quality implications. There was a serious air quality problem and it was about to get worse," he said.

The EPA entered into negotiations with DOE in an effort to put some limits on the RCS program. "In the midst of our negotiations," Repace continued, "Maxine Savitz [assistant secretary for conservation and solar at DOE] sent a letter to [EPA Administrator] Costle requesting the establishment of indoor air quality standards. As far as I was concerned, this was a very significant development. At that point we felt we could justify a big program, and that it was needed—it was of national importance."

Outside the agency, however, the view of how much will be done tends to be pessimistic. Hollowell, and to a lesser degree Spengler, claimed that the EPA is reluctant to touch the issue at all. Spengler cited arguments raised within the agency and by environmental groups that recognition of indoor air pollution would weaken the case for ambient standards, which have been hard fought for. And Hollowell suggested that the Geomet study and a National Academy of Sciences study commissioned by the agency were more an attempt to show that the EPA was doing something rather than part of an effort to truly take on the problem. It was the Savitz letter that goaded the EPA into taking charge as much as it has, Hollowell said: "It's become an issue that the EPA can no longer ignore."



Pollutant concentrations in a gas kitchen



Concentrations were measured in the center of a test kitchen, under varying ventilation conditions, while a gas oven was operated at 350 °F.
Source: G. D. Hollowell

Legal and political barriers

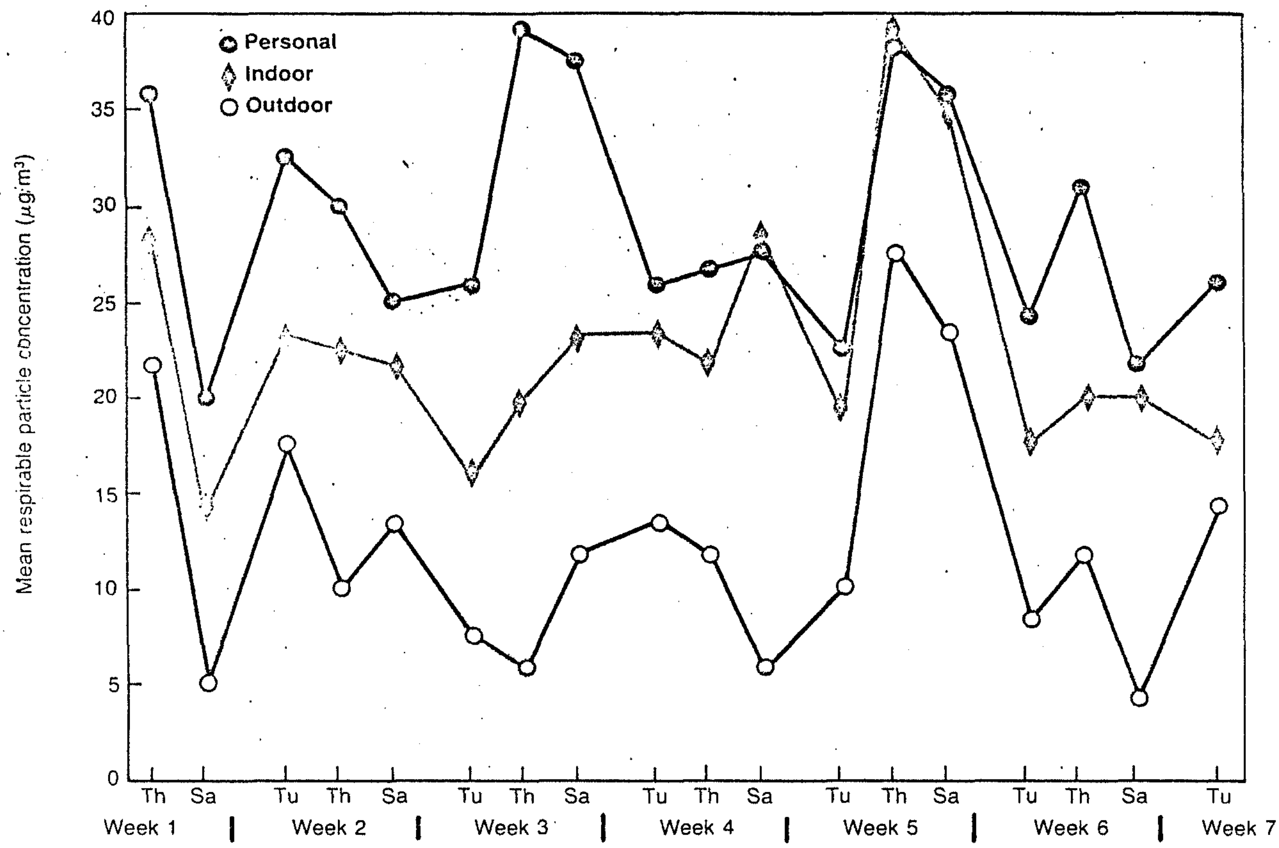
But even if the EPA does make the decision to tackle the issue, it faces some genuine obstacles. The so-called "industry argument"—that ambient standards may be weakened—is only one of them.

A more serious problem is that the EPA probably lacks legal authority to deal with indoor pollution, though the point is disputed. A clear mandate could come from an amendment to the Clean Air Act, an action that will be urged on Congress by a General Accounting Office report that was in preparation at press time.

There will no doubt be many "turf" problems as well, of which the EPA–DOE dispute over energy conservation is only the first. The Occupational Safety and Health Administration, the Consumer Product Safety Commission, the Department of Health and Human Services, and the Department of Housing and Urban Development are all already in the act in one way or another.

Finally, there is certain to be opposition from groups, such as the house builders, who would be affected by any eventual regulations and who will raise the "spectre of the government telling

Indoor, outdoor, and personal concentrations



Daily average concentrations for the entire group of 46 subjects in the Topeka study

Source: J D Spengler

people what to do indoors," as Repace put it.

But Repace once again tends toward the optimistic, dismissing these obstacles and declaring, "It is completely obvious to me that we will need indoor air quality standards." The extent to which his view is shared by his superiors is unclear.

Repace simply shrugs off the "industry argument." "If people are going to take your argument and use it against you, you can't stop them. And, to a certain extent, they have a point. But first of all, background levels indoors come from outdoors. Secondly, we know from a very large number of studies, you have acute cause and effect with factory emissions—people do die." And he made a point that both Spengler and Moschandreas emphasized when asked whether outdoor standards were important: "Some people spend the great bulk of their time outdoors." Spengler added that if it is peak exposures that determine the health effects, spending even a short time outdoors in the presence of high concentrations could be harmful.

As for worries over the EPA's telling people what to do, Repace said, "That is a very naive view. Controls can be implemented through changes in building codes rather than in personal behavior."

Airing views

In the meantime—and it may be a long meantime before these problems are sorted out—the EPA is seeking to have the RCS program limit its tightening up of residential buildings so that ventilation rates are not reduced below one complete air change per hour. The EPA has argued that the program intends to cut the average exchange rate in half, a move that would more than double indoor radon concentrations and would result in as many as 20 000 additional radon-induced lung cancer deaths per year. DOE argues that that is a gross overestimate, since the program would only reach 25–30% of the houses in the country and would only tighten them up by 25%, not 50%. Furthermore, they claim, the average ventilation rate is already below 1.0 exchange per hour. An agreement between the two agencies is expected shortly on the residential conservation program, but it will be a long time before there is any agreement on what the actual risks are. According to Hollowell, it will be a long time before we even know what the risks are.

"You just can't do it today," he said. "Setting a standard is not the way to go. But we're going to have to come up with some sort of trigger level" which will set off corrective action to reduce exposure.

Reduced ventilation unquestionably increases concentrations. Experiments by Hollowell's group have shown a direct relation between concentrations of CO, NO_2, and formaldehyde, produced by a gas oven, and ventilation rates in a test kitchen. Detailed measurements of radon in one house, under varying ventilation conditions, show a similar relation. And Hollowell has concluded that, for most cases, "an air exchange rate of 0.5 ach [air changes per hour] is required in order to maintain radon concentrations below 4 nCi/m^3, the maximum permissible given by health guidelines." Some energy-efficient houses have ventilation rates as low as 0.1 ach.

Air-to-air heat exchangers, which draw in fresh air through one duct while expelling indoor air in an adjacent duct, heat the incoming air and reduce the energy cost of ventilation; this may provide one, at least partial, solution. Control strategies for radon may include filters that remove airborne particles which carry the radon daughters. But according to Hollowell, "the whole control technology field needs a lot of work."

A monkey wrench in epidemiology

The control technology field isn't the only one. The finding of indoor sources and high indoor levels of pollutants has cast a shadow on past epidemiology, which attempted to relate health effects with outdoor levels only.

"The effects that you do see could be occurring at lower levels" than would appear from these studies, said Spengler. A typical epidemiological study might compare matched populations in two different cities, one with high outdoor concentrations of a pollutant and one with low outdoor concentrations; differences in morbidity and mortality between the two groups would then be ascribed to the different degrees of pollution. But indoor pollution can introduce several possible distortions. If, for example, a city with high outdoor levels of NO_2 used predominantly electric stoves while a city with low outdoor levels used gas stoves, actual personal exposures in both cities might be very similar. A study which looked only at outdoor levels would conclude that higher NO_2 concentrations had little effect on health. A systematic bias the other way is also possible, leading to an overestimate of the health effects.

Even if there is no systematic bias, however, the variation in indoor exposures introduces a "random variable" which reduces the sensitivity of the study. Hollowell asked the question on everyone's mind: "How can one do an epidemiology study and forget the indoor environment?"

Personal monitoring

Spengler sees this as a compelling reason by itself to study the indoor environment. "If it's a confounding factor in outdoor epidemiology, it's worth some investment—that's independent of it being a health problem of itself."

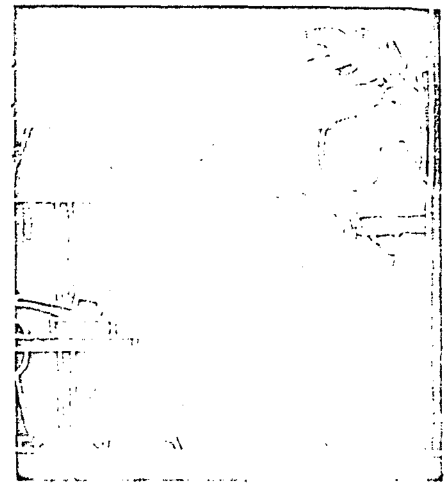
The ultimate aim for health studies on large populations, according to Spengler, is to see whether it is possible to "take one or two key variables, such as the presence or absence of gas stoves, and characterize the exposure of the whole population." In pursuit of this aim, Spengler has begun some personal exposure monitoring in conjunction with the Harvard Six City Study. Measurements made by portable samplers carried by the subjects are correlated with the subject's activities—recorded in a log—and with measurements taken at fixed locations indoors and out. One of these experiments, carried out in Topeka, Kans., shows some telling results: If outdoor concentrations of NO_2 and stove type are considered, 77% of the variance in recorded personal exposures can be explained; if only outdoor concentrations are considered, only 22% of the variance is explained. Spengler is in the process of extending these studies to the other cities of the Six City Study.

But expanding such a study to the point that it is more than a series of spot measurements—Spengler's Kansas study involved only 23 subjects—will be expensive and will be limited by available instruments. "Trying to develop low-cost, reliable, portable—if we could, even personal—monitors is the issue," said Hollowell. Both Hollowell and Spengler have had to design and build their own devices. The problem is not a lack of knowledge of how to measure these pollutants. ("Everything's available as far as principle of operation," said Spengler.) But instrument manufacturers have not yet found it worthwhile to produce units for the specific applications required. And portability and low cost are only a part of the issue: "The methods used to measure the same pollutants outdoors will likely encounter new interferences indoors," according to Spengler. Spengler ran into one such case when he attempted to use a commercial NO_2 monitor indoors. Everything was fine until house painters arrived on the scene; as soon as they started work, the meter went off scale.

An expensive study

There is a growing sentiment that a large study is needed. As Moschandreas said, "One house does not focus on the big problem. We are not there yet. We cannot make general conclusions." Whether the money will be available for the "comprehensive, statistically valid study" that Moschandreas envisions is another matter.

At present it seems that $3–4 million may be budgeted by the EPA for fiscal year 1982. In the meantime, the DOE indoor air quality program at Lawrence Berkeley will continue at a budget of about half that, as it has for several years; and $2 million is being made available to the EPA immediately through a two-year agreement with the National Institute for Occupational Safety and Health. NIOSH's



interest is in having 24-h exposure profiles developed for workers in the electronics and biosynthesis industries; the EPA expects to learn something about general indoor exposures to radon, formaldehyde, respirable particles, and asbestos in the course of the work.

Indoor atmospheric chemistry

More is needed than a large survey of indoor concentrations. What is in the air in the first place is still a major unknown, particularly in the case of organics. "Organics from building materials is still an area that has not really been explored," said Hollowell. "I don't think we really understand what all the sources are"—or even what the identities of all the compounds are.

How indoor pollutants interact is also an unknown. Compared with the outdoor environment, said Spengler, "you're injecting into the air totally different characteristics of temperature, humidity, and other pollutants." Ammonia, produced by humans, should be higher indoors, for example, and could react with sulfates or sulfuric acid. The question is: What is the chemical species that ends up inside?

"The other thing that's missing is quantification of removal rates," Spengler continued. "You have tremendously more surface area indoors; you have much more opportunity for surface reactions." Particle deposition rates, room-to-room air-transfer rates, and ventilation rates need to be known better too.

No one is underestimating the size of the task. "I see a need for a major program that should take somewhere from three to five years," said Moschandreas. And there is an understanding that all available resources will need to be tapped. "None of us can do the whole thing," he said.

—Stephen Budiansky