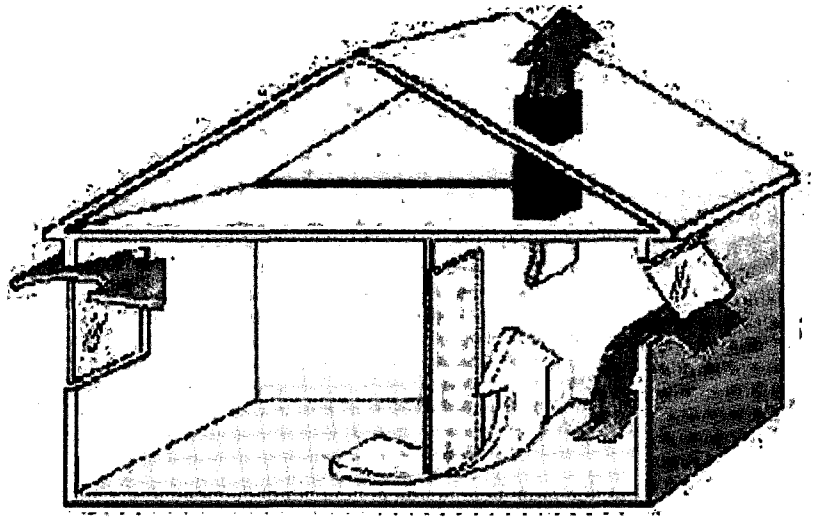
Ernest Orlando Lawrence Berkeley National Laboratory

Environmental Energy Technologies Division

Indoor Environment Program

1996 Annual Report



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Indoor Environment Program
1996 Annual Report

Joan M. Daisey, Program Head

Environmental Energy Technologies Division
Ernest Orlando Lawrence Berkeley National Laboratory
University of California
Berkeley, CA 94720
(510) 486-5001

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Indoor Environment Program

The forty-five chemists, physicists, biologists, architects, engineers, staff, and students of the Indoor Environment Program are all working to solve the problems of indoor air quality, health, comfort, and energy use associated with the indoor environment. A common thread throughout this work is the importance of ventilation — both for its role in supporting human health and comfort as well as for its liability in requiring large amounts of energy to heat and cool it.

The importance of understanding these interactions can be illustrated by two examples: the health and productivity of workers (Fisk and Rosenfeld, 1996) and the performance of sensitive equipment in clean room environments (Faulkner, *et al.*, 1996). During the past year, we estimated the magnitudes of health and productivity gains that may be obtained by providing better indoor environments (see table). The ratio of the potential financial benefits of improving indoor environments to the costs of the improvements ranges between 20 and 50.

A second example is from our Clean Room Energy Efficiency Study: Clean rooms utilize large amounts of electricity to operate fans that recirculate air at very high flow rates through particle filters. Usually, the fans operate continuously at full speed, even when the clean room is unused. To reduce the energy use in a research clean room, the rate of air recirculation was controlled in response to real-time measurements of particle concentration. With this new control system, fan energy use decreased by 65% to 85% while maintaining particle concentrations below the allowable limits except during occasional one-minute periods. The estimated payback period for this technology is one to four years.

Highlights from 1996

Energy Efficiency — Single-Family Residential Buildings

A major effort has been to characterize single-family residential ventilation liabilities for the U.S. by climate and housing characteristics. Blower door measurements of the air tightness of single-family dwellings, collected from state weatherization programs, were used with the LBNL infiltration model to estimate national ventilation energy liabilities. There are significant differences among climate zones (see figure).

Newer houses are more airtight and energy efficient than older homes. Weatherization programs targeted at older houses in colder climates offer the potential to reduce ventilation energy by about 2.6 Quads annually (about 30% of residential energy use) while still

Improvement in indoor environmental quality	Potential U.S. annual savings or productivity gains (1993 $US billions)
Reduced respiratory disease	$6 - $19
Reduced allergies and asthma	$1 - $4
Reduced "sick building syndrome"symptoms	$10 - $20
Improved worker performance from changes in thermal environment; changes in lighting	$12 - $125

Research Overview

Our research can be divided into three areas:
1) Projects that have energy efficiency as their focus,
2) Activities that study the dynamic behavior of indoor air pollutants — radon, volatile organic chemicals, and environmental tobacco smoke, as well as the development of air quality control technologies,
3) Investigations into the exposure and risk associated with pollutants, and methods to reduce risks. Examples of some of our research activities within each of these areas are listed below:

Energy-Efficiency

- Energy and ventilation liabilities in single-family housing
- Thermal energy distribution systems
- Multizone buildings
- UV Waterworks

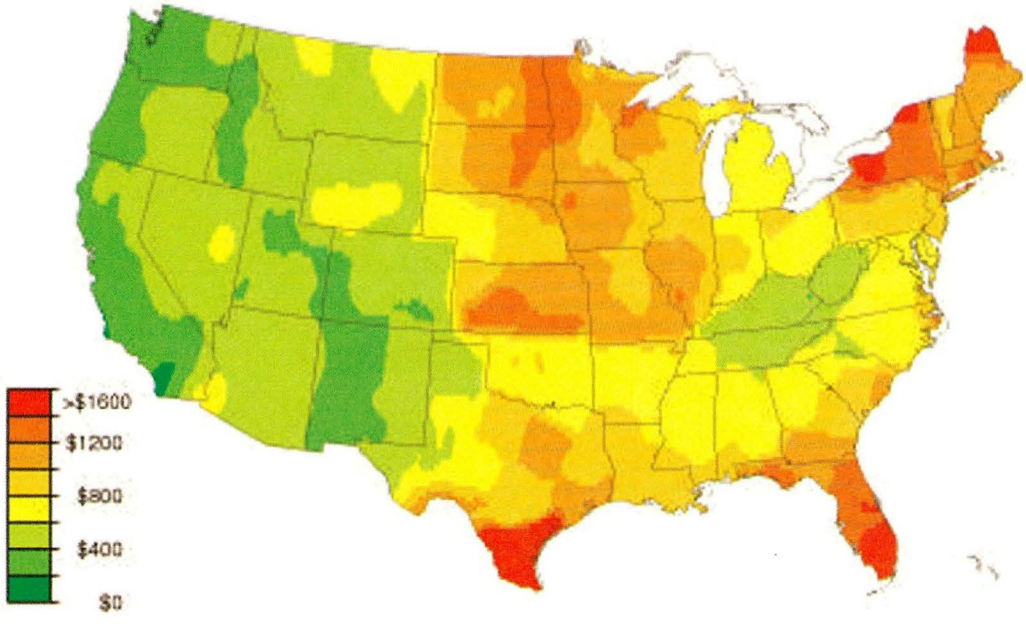
Indoor Air Quality

- Indoor air quality in new houses
- Radon entry into buildings
- Transport of volatile organic compounds in contaminated soil gas into buildings
- Environmental tobacco smoke

Exposure and Risk Analysis

- The High Radon Project
- Carbon monoxide passive dosimeter
- Tritium exposure and risk aassessment

Estimated annualized cost of infiltration and ventilation in U.S. single-family residences



meeting the ASHRAE standard for ventilation and indoor air quality (Sherman and Matson, 1996).

Energy Efficiency— Multizone Buildings

There are approximately 1 million apartment buildings and over 4 million commercial buildings in the U.S. Assessments of potential energy savings from reduced ventilation are more difficult and challenging to estimate for such buildings; however, some of the tools we have developed, such as the MultiTracer Mass Spectrometer, for short-term measurements, and the use of distributed tracer diffusion sources as a low-cost, convenient measurement method for longer periods, will be useful in these efforts. Research in a multistory residential building in Chelsea, MA, has shown that unbalanced airflows can lead to substantial heat losses as well as air quality problems (Diamond, *et al.*, 1996). The Chelsea building was modeled using the COMIS multizone airflow model previously developed in the Program (Feustel, 1996). To characterize the effectiveness of ventilation in controlling indoor pollutant concentrations in large buildings, we have developed a new, convenient index of ventilation, the Pollutant Concentration Index.

Energy Efficiency — Thermal Energy Distribution

Previous research demonstrated that reducing energy losses associated with thermal-conditioning duct systems is a significant opportunity to reduce energy use. Air leaks in duct systems, as well as heat gains and losses, have been measured and characterized. An internal access duct sealant technology, based on injection of aerosol into the ducts, was developed to cost-effectively eliminate duct leakage. Over the past year, protocols for aerosol sealing were successfully field-tested in more than 200 houses. Field measurements, in combination with laboratory experiments, have demonstrated that the seals last for at least 2 to 4 years and that the technology is cost-effective. In addition, a protocol for estimating residential thermal distribution system efficiency from measurements of duct leakage and simple system descriptors has been incorporated into a draft ASHRAE standard (152P). This standard is being incorporated into the California regulations for Home Energy Rating Systems. Efforts to commercialize the duct sealant technology for residential buildings have been initiated and applications of the technology in small commercial buildings will be an important research and technology development focus over the next few years. (Modera, *et al.*, 1996; Walker, *et al.*, 1996; Jump, *et al.*, 1996.

Energy Efficiency — UV Waterworks

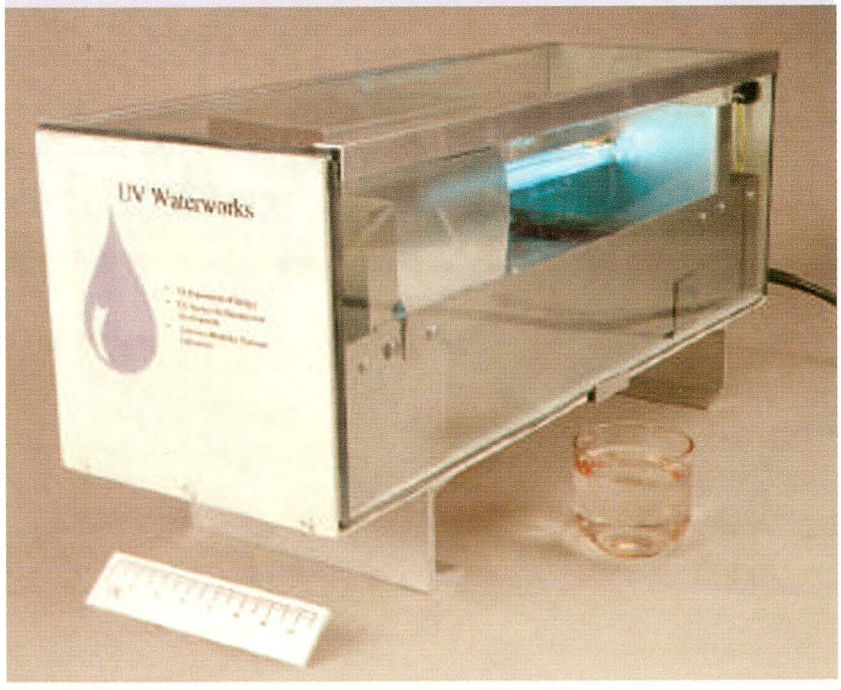
In the developing world, waterborne diseases, *e.g.*, cholera and dysentery, kill more than 400 children worldwide every hour and result in the loss of billions of hours of worker productivity. Disinfecting water by boiling it over cookstoves increases the burden on those collecting the fuelwood — mostly women and children — and also places stress on the biomass resources. Gathering wood also occupies time that might be spent productively in other activities. To address this significant public health and energy problem, we developed a water-purification system that uses an ultraviolet light that is durable, easy to use, inexpensive, and can be constructed and maintained locally. The prototype device, called UV Waterworks, can disinfect drinking water for 2¢ per ton of water, including the cost of electricity and consumables and the annualized capital cost of the unit (see Figure). Its first cost is about $300, and, using only 40 watts of electricity, provides four gallons of disinfected drinking water per minute. The disinfection process uses approximately 20,000 times less primary energy than the standard alternative of boiling water over a cookstove. The UV Waterworks is now being field tested (Gadgil, *et al.*, in press).

Indoor Air Quality

Indoor Air Quality in New Houses

Research on residential ventilation liabilities indicated that newer, more energy-efficient houses are much more airtight. During 1996, we began investigating the indoor air quality of such houses. Measurements in five houses (in three states) indicated that this sample of houses was much tighter than older housing, with air exchange rates ranging from less than 0.1 to 0.45 air changes per hour. Indoor concentrations of formaldehyde were generally below 0.05 ppm, a level at which less than 1 % of the population is expected to experience irritant symptoms. The measurements indicate the success of energy-efficient building codes in reducing air leakage and the successful efforts of manufacturers to reduce formaldehyde emissions from building materials and furnishings. However, abnormally high concentrations of total volatile organic compounds (TVOC), up to 12 mg/m^3, were measured in several houses. High concentrations of odorous and irritant compounds were found to persist over a period of up to two years in two other houses. The sources and building practices that produced this problem are under investigation.

UV Waterworks Water Purifier



Radon Entry into Buildings

In 1996, we completed our multi-year research to develop an understanding of the advective transport of radon in soil gases into houses. When we began this effort, the models underpredicted actual radon entry rates into an experimental basement by almost a factor of ten. Through development of the dual-probe soil permeability measurement method and improved modeling, the difference between model and measurement was resolved to within a factor of two (Garbesi, *et al.*, 1995). In the past year we completed research on radon entry into buildings driven by atmospheric pressure fluctuations, a previously neglected entry process that helps to explain the higher-than-expected radon concentrations during the summer (Robinson, *et al.*, 1997). We also completed experiments demonstrating that passive stack radon mitigation systems can fail because the pressures generated at the roof of a house by wind. We have also developed new, energy-efficient radon mitigation technologies. Field tests have demonstrated that these new control technologies use approximately 30% of the energy of conventional radon mitigation technologies. (Fisk, *et al.*, 1995).

Transport of VOCs in Contaminated Soil Gas into Buildings

Volatile organic compounds (VOCs) in contaminated soil gases can also be advectively transported into buildings. At a site contaminated with gasoline, we found evidence that microbial degradation can greatly reduce the concentrations of VOCs that enter into a building. There, a low diffusivity layer with a microbial population restricted the flow of gasoline vapors into the building. In and above this layer, it appeared that a microbial population consumed a substantial fraction of the gasoline vapors that diffused from deeper in the soil. The remaining contaminants were drawn into the building from the subslab region as a consequence of building depressurization caused by wind on the building, and also entered the building by diffusion through the slab floor (Fischer, *et al.*, 1996).

Environmental Tobacco Smoke

We have continued research to understand the dynamic behavior of environmental tobacco smoke (ETS), a complex mixture of particles, gases, and vapors, in indoor environments (Daisey, *et al.*, 1996). We found that 80% or more of the nicotine emitted from cigarettes, a widely used tracer for ETS, is rapidly deposited onto walls, ceilings, and floors, with some re-emission of airborne nicotine as the room is ventilated (Van Loy, *et al.*, 1996). We also observed rapid surface deposition losses of other semi-volatile organic compounds in ETS. It has commonly been assumed that the chemical composition and toxicological properties of ETS and sidestream smoke, from which ETS originates, are equivalent. These results indicate that toxicological experiments and exposure assessments based on this assumption are seriously flawed. In related studies, we demonstrated that 3-ethenylpyridine and pyrrole are good tracers for estimating the contributions of ETS to the VOC concentrations in buildings with smokers (Hodgson, *et al.*, 1996).

Exposure and Risk Analysis

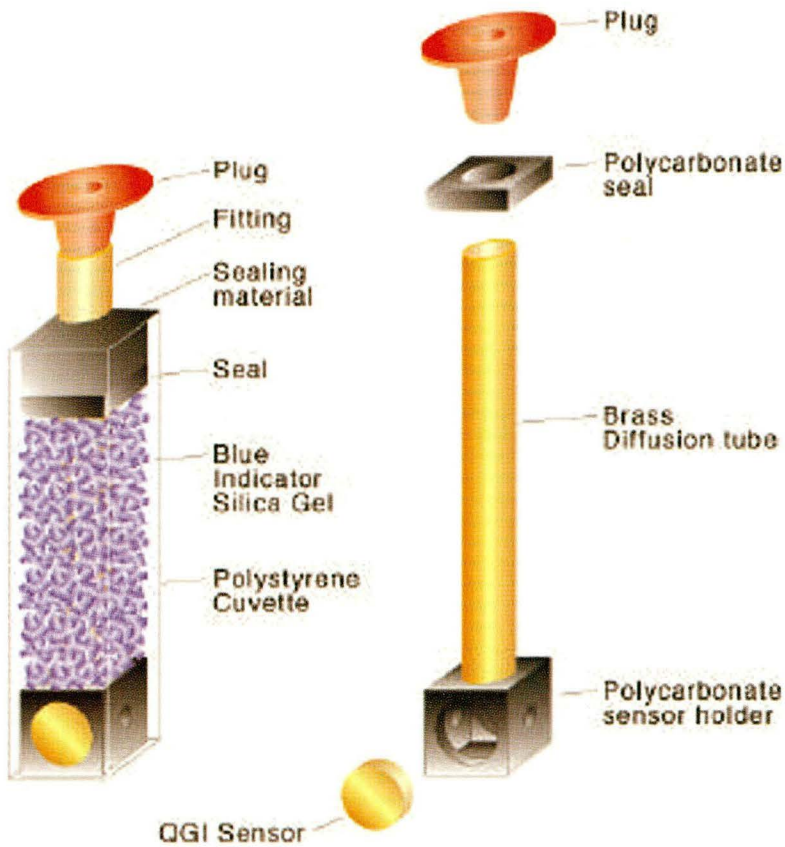
The High Radon Project

The high radon project has successfully developed a new statistical methodology to identify counties and smaller areas of the U.S. most likely to have very high indoor concentrations of radon, e.g., equivalent to occupational exposures. This statistical approach uses existing information on geology, housing characteristics, and meteorology, with existing, but very limited, radon concentration data. The methodology will enable states to target their radon mitigation efforts to areas likely to have the highest exposures. In 1997, we will begin transferring this new methodology to state health departments (Price and Nero, 1996, Price, *et al.*, 1996).

Carbon Monoxide Passive Dosimeter

A field model of a passive occupational dosimeter for carbon monoxide was designed and developed this year (Figure 3). The dosimeter has a range of 10 to 800 ppm-hours, an accuracy of ±20% and a precision of ±10 ppm-hour. Low emission materials were tested and selected for use in the body of the dosimeter and the holder for the sensor disk was redesigned. Interferences from other indoor air pollutants are being investigated and field tests are planned for early 1997. The dosimeter cost is estimated to be under $20 when fully developed and commercialized.

LBNL/QGI carbon monoxide passive occupational dosimiter



Tritium Exposure and Risk Assessment

We are working with the Environmental Health and Safety Group at LBNL to develop a site-specific model to assess both occupational and residential exposures and health risks associated with LBNL tritium releases. This model includes environmental transport, indoor/outdoor exposure assessment, pharmacokinetics/metabolism, and radiological risk components. In 1996, we carried out detailed statistical comparisons of the performance of the model against a significant amount of relevant site-specific data including measured levels of tritium in air, rainwater, soil, runoff, ground water, soil, vegetation, grazing animals, and urine levels from workers in several buildings. The modeled values were in very good agreement with measured values. These results support the model premise that the soil acts as a reservoir controlling air concentrations of tritium (McKone, and Brand, 1996)

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