LAWRENCE BERKELEY NATIONAL LABORATORY

SUMMER 2004
VOLUME 5 NUMBER 3

Environmental Energy Technologies Division

NEWS

ADVANCED ENERGY TECHNOLOGIES | ATMOSPHERIC SCIENCES | BUILDING TECHNOLOGIES | ENERGY ANALYSIS | INDOOR ENVIRONMENT

Dampness and Mold Growth in Buildings: A National Academy Study

Figure 1. Mold in lab cultures (Photo courtesy of Mike McNickle)

Mold growth in buildings and its possible effects on human health have been in the news for several years while claims against insurance companies for mold and moisture-related problems in buildings have been on the rise, as has mold-related litigation. A recent report by the National Academy of Sciences Institute of Medicine has concluded that strong scientific evidence links mold and damp conditions in buildings to some health effects.

Damp Indoor Spaces and Health, authored by a committee of the same name, was released at the end of May. William Fisk, Senior Staff Scientist and Head of the Indoor Environment Department (IED) in the Environmental Energy Technologies Division (EETD) at Lawrence Berkeley National Laboratory (Berkeley Lab), was a member of the committee. Along with eight other committee members, including Committee Chair and Dean of the University of Michigan School of Public Health Noreen Clark, Fisk participated in an extensive review of the available scientific literature on the subject.

"The committee concluded that there is robust scientific evidence of an association of increases in selected respiratory health effects with building dampness or visible mold," says Fisk. "These health effects are asthma exacerbation in sensitized individuals, and cough, wheeze, and upper-respiratory symptoms in otherwise healthy individuals. The committee also said that building dampness is an important public-health problem because dampness and mold problems are present in a significant fraction of buildings and linked to substantial increases in these health effects.

"However, the committee believes that the existing evidence is insufficient to conclude that there is a *causal* relationship between dampness or mold and increases in these health effects. For example, moisture itself is not directly causing the adverse health effects, and it is not certain whether exposures to molds or to some other pollutants found in damp buildings actually cause the observed increases in adverse health effects."

Why is Dampness a Concern?

Dampness in buildings is a concern because it often leads to growth of molds and bacteria and to increased emissions of chemicals from building materials. In addition, dampness

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causes structural degradation of buildings. Dampness in buildings has a number of causes. The report argues that the way to reduce both dampness problems and the risk of associated health effects is to improve the design, construction, operation, and maintenance of buildings.

Figure 2. *Some mold is hidden from view, such as the mold shown in this image, which was discovered when cabinets were removed from a wall (Photo courtesy of Mike McNickle)*

"There is considerable existing knowledge about how to make these improvements that is underutilized," says Fisk. "For example, many dampness problems are caused by simple water leaks in roofs, walls, and plumbing systems that can be prevented or rapidly corrected through building maintenance."

"Toxic molds" in buildings are a specific concern that is not well understood. These molds can, under certain conditions, produce agents called mycotoxins. "Cellular and animal studies have shown that mycotoxins can be highly toxic," says Fisk. "However, we do not know what levels of exposure are necessary to cause health effects in humans, nor the amount to which people are exposed in mold-contaminated buildings."

Figure 3*. A living room in a San Francisco apartment in which the tenant never opened the windows (for security reasons) (Photo courtesy of San Francisco Department of Public Health)*

Research Needs

The National Academy committee identified a long list of research needs related to damp buildings and mold. One need is for a better method to measure people's exposures to dampness-related pollutants. "We also need a better fundamental understanding of how people are actually exposed to microbial agents," says Fisk. "For example, does resuspension of mold spores from floors (as people walk over them) contribute substantially to exposures? The effect of dampness on several types of health problems needs much further research. The health benefits of mold remediation also need to be better understood."

Despite some uncertainties about molds, dampness, and their health effects, the committee concluded that dampness is an important public-health problem and suggested that education, training, and incentives for reducing dampness should be elements of a public-health response.

Berkeley Lab's Contributions

In general, most dampness and mold research has been performed in homes. However, Mark Mendell, an IED epidemiologist, is analyzing data from office buildings to assess whether dampness in those buildings increases the risk of adverse health effects. A recent analysis performed in collaboration with the California Department of Health Services found that increases in lower-respiratory and mucous-membrane symptoms were linked to particularly high airborne concentrations of molds and bacteria that grow on damp building materials.

IED has investigated the relationship between air-conditioning systems and health effects. On average, occupants of air-conditioned buildings have higher rates of a variety of respiratory and other health symptoms. The explanation for this correlation is not clear; one hypothesis is some air-conditioning systems become contaminated with microbial agents transported into the building's occupied spaces. In analyses of data from 80 office buildings where occupants complained of respiratory and related problems, evidence of wet, dirty air-conditioning systems was associated with increased lower-respiratory symptoms such as wheeze and shortness in breath.

In addition to contributing to research on health effects, the IED investigates how pollutants are transported within buildings, the mechanisms and amounts of pollutant exposure in buildings, and the effectiveness of technologies and practices for reducing pollutant exposure in buildings. IED researchers are particularly interested in technologies or practices that can simultaneously improve indoor environmental quality and save energy.

Advice to Homeowners

Fisk offers some suggestions on how to prevent mold from becoming a problem in homes. "The key to prevention," he says, "is to design, construct, operate, and maintain homes in a way that prevents building components and furnishings from becoming unusually damp. Some causes of dampness problems are complex and must be identified and addressed by building experts," he

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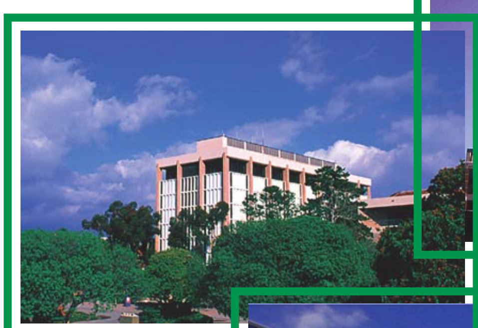
EETD to Operate Demand Response Research Center for California Energy Commission

The California Energy Commission (CEC) is funding a new Public Interest Energy Research (PIER) Demand Response Research Center (DRRC) that will be managed by the Environmental Energy Technologies Division (EETD) at Lawrence Berkeley National Laboratory (Berkeley Lab). The CEC will give $8 million over three years to the new center, which will be directed by EETD scientist Mary Ann Piette.

Demand response (DR) facilitates rapid, automatic reduction of energy use in buildings, industrial facilities, and homes when power prices increase or an emergency arises on the electricity grid. "Demand response refers to using technologies, programs, and policies, which allow building owners and managers to reduce their electrical use rapidly, in response to a jump in the price of electricity or a threat to the electric grid," says Piette. "Berkeley Lab recently tested the first automatic multi-building demand response technology using internet connectivity" (see http://www.lbl.gov/Science-Articles/Archive/EETD-demand-response.html).

"With the opening of this research center," Piette adds, "the California Energy Commission has taken another concrete step to making demand-response programs a reality in California. The commission recognizes that demand response offers the state a powerful, rapid, market-based response to growing electrical demand." The Center will initiate planning through a scoping study to be completed in fall 2004.

"Demand response will prove to be a boon to the electricity supply picture in California in times of distress," says state Energy Commissioner Arthur Rosenfeld. "When combined with conservation and energy efficiency, demand response can both lighten the burden on the electricity grid and help stabilize peak pricing when supply becomes scarce and the demand margin becomes dangerously narrow."



Large commercial users who participate in DR programs create a plan to reduce electrical loads of their choice; the plan is executed in response to an automatic signal of a power-price increase or grid emergency. For example, users can decide in advance to dim or turn off lights, lower hot-water temperatures, reduce air-conditioning use, or shut down certain assembly lines or tools.

Being able to respond to electricity price signals in real time can save power users money, reduce energy consumption, and lower energy prices by making the power market more responsive to consumer needs in real time. However, the technology to implement DR programs in the U.S. is only beginning to be available, and much remains to be learned about how to most cost-effectively implement DR programs. In addition, DR has been identified as an important element of the State of California Energy Action Plan, which was developed by the CEC, California Public Utilities Commission, and Consumer Power and Conservation Financing Authority.

"The new research center will serve as a focal point for demand response research in California," says Piette. "Institutions from the around the state and the country will be eligible to propose and conduct R&D with center funding."

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EETD to Operate Demand Response Research Center for California Energy Commission

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Piette will oversee management of the research portfolio and facilitate a Partners Planning Committee which will, with the CEC, determine the center's direction.

The DRRC will support research in four areas:

- Policies, programs, and tariffs: DR can be designed as an emergency response (i.e., in case of grid overload) or a price response (e.g., dynamic tariffs). Research needs in this area include improving our understanding of how customers respond to price changes versus emergencies and improving current methods of measuring energy savings from DR programs.
- Utility markets, technology, and systems: This area includes intelligent and integrated systems for DR control and models of how DR programs affect the reliability of the electric power grid. Also needed are financial engineering models, such as option valuation models, to estimate the value of DR.
- Customer and end-use technology and systems: A simple example of a project in this area would be the development of an easy-to-use computer-based system showing the energy savings possible from implementing certain energy reductions at a given price of electricity.
- Consumer and institutional behavior: Studies in this area address how people interact with the energy system and how energy meets the needs and desires of people and businesses. An example would be a study examining which incentives bring customers into a DR program and which incentives will keep customers in the program over the long run.

An important feature of the new center will be its close ties to stakeholders, including control, metering, and information system developers; electric power utilities; policy makers; building owners, engineers, and operators; and building equipment manufacturers.

—Allan Chen

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For more information on the Demand Response Research Center, see http://drrc.lbl.gov

This research is funded by the California Energy Commission's Public Interest Energy Research Program.

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adds. "If you see evidence of significant dampness, such as water stains or water-damaged building materials, you should rapidly take actions to correct the cause of the problem. Often these require the assistance of a building professional, for example, a roofing company for a roof leak."

Some causes and solutions are obvious. When a plumbing fitting under the sink starts leaking, the homeowner can tighten or replace it. Dehumidifiers as well as bathroom and kitchen fans that exhaust air to outdoors can help prevent dampness problems in some situations, but these are not the solution to problems such as leaky pipes, roofs, or windows.

When building materials become wet from a sudden leak or spill, they should be dried as quickly as possible, within hours or a couple of days—not weeks—to reduce the risk of mold growth, Fisk advises. Outside experts will normally be required to dry buildings after large leaks or floods.

"When visible mold is present," says Fisk, "it should be removed by cleaning. When cleaning is not possible, the mold-contaminated materials should be removed. Homeowners can use normal cleaning practices to remove small amounts of mold, such as the moldy spots in the shower, but widespread mold contamination should be addressed by professionals. The most important message to remember," he concludes, "is that controlling building dampness is the key to preventing mold contamination."

—Allan Chen

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For the National Academy report, see: http://www4.nationalacademies.org/news.nsf/isbn/0309091934?OpenDocument

There are numerous sources of information on mold control for homeowners. For example, see the U.S. EPA site: http://www.epa.gov/mold/moldresources.html

This work was funded by the National Academy of Sciences.

Transition-Metal Switchable Mirrors Win 2004 R&D 100 Award

In July, R&D Magazine *announced that transition-metal switchable mirrors, a technology developed by researchers in the Environmental Energy Technologies Division (EETD) at Lawrence Berkeley National Laboratory (Berkeley Lab), had won an R&D 100 award. The following article, first published on Berkeley Lab's* Science Beat *website (http://www.lbl.gov/Science-Articles/Archive/sb-Apr-04-EETD-switchable-mirror.html), describes the technology and its potential for next-generation energy-efficient windows as well as other applications.*

The race is on to develop the next generation of energy-efficient windows, and it has a new entrant: transition-metal switchable mirrors (TMSMs). TMSMs are glass panels with a coating that can switch back and forth between a transparent state and a reflective one. The new coating was developed by Thomas Richardson of EETD with assistance from Jonathan Slack.

Figure 1. *Transition-metal switchable mirror windows vary from transparency to heat and light (top half of this sample), to being almost wholly reflective (bottom)*

Controlling the flow of solar radiation through windows to building interiors by use of existing low-emissivity (low-e) technology has already saved billions of dollars in energy costs—$8 billion through the year 2000, according to a 2001 study by the National Academy of Sciences. Low-e windows are the first generation of energy-efficient windows, developed by Berkeley Lab and its commercial partners during the 1980s. The coatings on these windows prevent some heat from reaching a building's interior, which reduces air-conditioning use; they also trap heat inside during cold periods to save heating energy.

A substantial research effort is under way in the U.S. and abroad to develop the next generation of efficient windows using dynamic technologies, which change characteristics in response to climate conditions, e.g., reducing transmission of light and heat through a window by turning darker when the sun is high and becoming transparent when more light is desired. One type of dynamic technology already being tested at Berkeley Lab and elsewhere is the absorbing electrochromic (AE) window, which switches from a transparent state to a darkened state, usually blue in color.

Thin Metal Films on Glass

The latest dynamic window technology is the switchable mirror, (Figure 1) which uses thin-film coatings that can be converted from a transparent to a reflective state and back again by application of an electric field (electrochromic switching) or by exposure to dilute hydrogen gas (gasochromic switching).

"The film used for the Berkeley Lab switchable mirror is made of an alloy of magnesium and one or more transition-metals," says Richardson. "These make a new generation of electrochromic windows possible, superior in many ways to the current generation because they reflect visible and infrared light and heat instead of absorbing it." Current electrochromic windows have little effect on infrared radiation, which accounts for almost half of incident energy. Figure 2 illustrates the structure of absorbing and reflecting EC windows.

TMSMs perform better than AE windows in a number of other ways as well. The greater dynamic range of transition-metal switchable mirrors, both in transmission (from 50 percent to 0.5 percent or lower, a factor of 100) and in reflection (from 75 to 10 percent reflective) gives them considerable advantages over AEs in user comfort and energy savings. In addition, unlike AEs, TMSMs can become completely opaque to provide interior privacy.

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Transition-Metal Switchable Mirrors Win 2004 R&D 100 Award

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Richardson adds that "the use of transition-metals instead of rare-earth metals" in the Berkeley Lab TMSMs "could also significantly lower the cost of these windows." Switchable mirrors based on rare-earth metals were developed in 1996 in Europe. Rare-earth thin films are significantly more expensive and difficult to prepare and may degrade more readily than the Berkeley Lab transition-metal films.

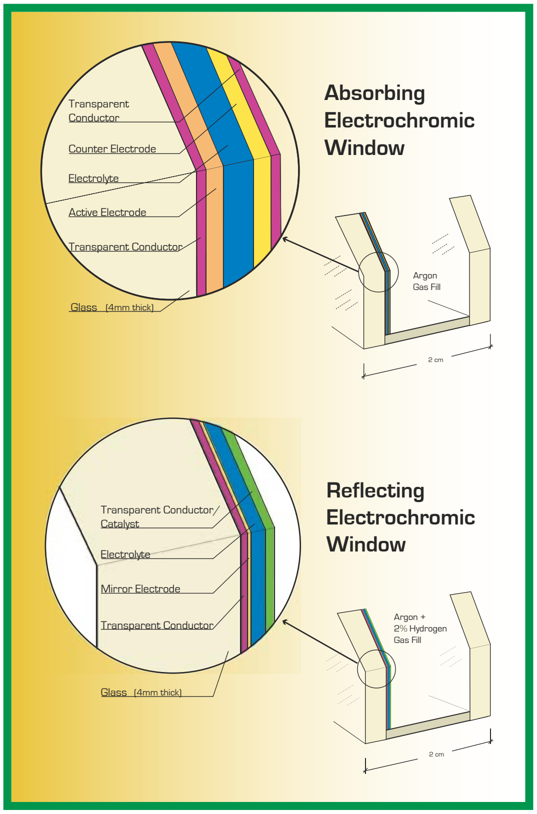

Figure 2. *Schematic drawing of absorbing and reflecting electrochromic window structure*

"TMSMs should also be easier to manufacture, because they use fewer and thinner coatings than absorbing electrochromics, which employ thick oxide layers," says Richardson.

TMSMs in Your House — and in Your Car

The primary application of TMSMs is as dynamic, energy-efficient window coatings for architectural glass. Dynamically controlled windows respond to changes in sunlight conditions in real time through the use of light sensors and control technology. When the sun is bright, TMSMs switch to a highly reflective state; in lower-light conditions, such as cloudy periods or early and late in the day when the sun is low, the windows switch to a partially reflective, partially transparent state to admit some daylight. Dynamic windows can be regulated automatically throughout a building, but occupants can also have local control over their windows, from their personal computers, for example.

The electrical current that accomplishes the switching in TMSMs is extremely small compared to the energy use of lights and air conditioners, so the potential energy savings from these windows are enormous. Coupled with an automatic sensor and control system, dynamic coatings not only minimize energy use but maximize comfort as well, reducing heat gain and controlling glare.

"The technology can also be used in transportation, as a dynamic window for automobiles, aircraft, and ships, as well as in helmets for pilots, cyclists, and motorcyclists," says Richardson. The technology could improve glare control in motorcycle and flight helmets, airplane and marine windows, cabin partitions, and sunglasses which would increase safety for vehicle operators. By reflecting some of the sunlight falling on a car's windows and sunroof, TMSMs can lead to a reduction in the size and weight of car air-conditioning units, which in turn reduces fuel use.

Richardson notes that the technology can also be used "in optical displays, electronic data switching, and sensors." In data switching, TMSMs can route signals through fiber optic networks; as electrochromic outer coatings, they can modulate the propagation of light through fibers. And, says Richardson, "Engineers may use TMSMs as temperature-regulation coatings for satellites, which need to control solar heat gain while in orbit to protect interior circuits."

Possible Energy Savings

In the U.S., residential buildings alone currently lose more than 1.7 quadrillion British thermal units (Btus) per year. Berkeley Lab researchers estimated in 1996 that the potential energy savings from accelerated adoption of existing energy-efficient windows could amount to more than 25 percent of the energy lost through windows.

"Dynamically controlled windows can provide greater energy savings than existing passive window technologies, so it is reasonable to expect that windows based on TMSMs could save more than 25 percent of the energy lost through conventional windows in homes and commercial buildings," says Richardson. These savings could be worth billions of dollars per year.

—Allan Chen

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TMSMs have received U.S. patent #6,647,166. Contact Pam Seidenman at PSSeidenman@lbl.gov in Berkeley Lab's Technology Transfer Department for information about licensing transition-metal switchable mirror technology.

http://www.lbl.gov/tt/techs/lbnl1665.html

http://windows.lbl.gov/materials/chromogenics/hydrides.htm

This research is funded by the U.S. Department of Energy's Office of Energy Efficiency and Renewable Energy.

TRAMS: A New Tracer Gas Airflow Measurement System

The technologies currently available to measure airflow rates in duct systems require careful use and substantial time to produce accurate measurements. Traditional measurement systems use Pitot-static tubes or hot-wire or other anemometers to measure velocities at several locations in the cross section of an airstream. It very difficult to accurately measure airflow rates using these methods because of problems such as large spatial variation in air velocities and air velocities that are so low that they approach the detection limit of the anemometers.

If a tracer gas is injected into a duct at a known rate and the true average concentration of tracer gas upstream and downstream of the injection plane can be determined, the flow rate is calculated from a simple mass-balance equation. However, the application of tracer-gas methods has been limited because of poor mixing of the tracer gas in the airstream, the high cost of the systems, and the substantial time required to perform measurements.

The Indoor Environment Department (IED) of the Environmental Energy Technologies Division (EETD) at Lawrence Berkeley National Laboratory (Berkeley Lab) has invented a new tracer-gas measurement method that overcomes these limitations. The Tracer Gas Airflow Measurement System (TRAMS) will have a range of applications, including balancing of airflows in heating, ventilation, air conditioning (HVAC) systems in commercial buildings; diagnosis of HVAC systems for identification of energy-efficiency opportunities; and calibration of in-place airflow measurement stations.

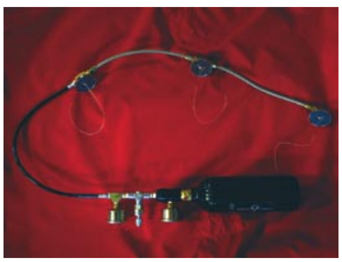

***Figure 1**. The whip injector; note the small, light weight CO_2 cylinder*

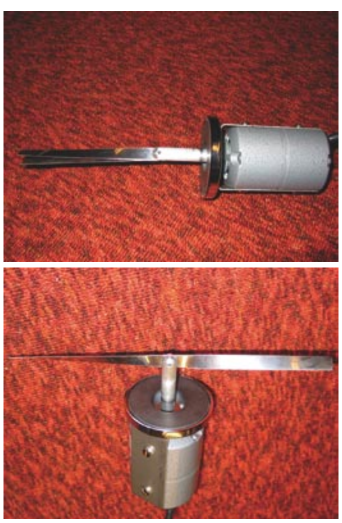

***Figure 2**. The mixing fan, with blades folded for insertion in the duct (top) and with blades unfolded*

Description

TRAMS uses carbon dioxide (CO_2) as its tracer gas for a number of reasons: CO_2 is inexpensive, non toxic, and widely available in cylinders, and CO_2 analyzers are much less expensive than the analyzers used for conventional tracer gases, such as sulfur hexafluoride. To ensure that injected CO_2 mixes effectively in the airstream, TRAMS uses "whip" injectors (Figure 1). These injectors are very small, flexible tubes that are easily installed in duct systems and emit CO_2 at high velocity, which causes them to whip around rapidly in the airstream, dispersing the tracer gas. Easily insertable fans (Figure 2) with fold-up blades and externally mounted motors help mix the tracer gas with the airstream. The soaker-hose sampling system for the CO_2 analyzer allows a user to easily collect samples.

Advantages

The major advantages of the TRAMS system are:

- Its unique mixing and sample-averaging techniques effectively mix CO_2 in the airstream within two hydraulic diameters of the injection site.
- TRAMS uses a gas analyzer that costs one tenth the price of most other tracer-gas analyzers.
- TRAMS does not require a mass-flow controller to regulate the tracer- gas injection, which makes operation simple and minimizes costs.
- The TRAMS apparatus is easy to install and not intrusive. Each injector requires only a ¼-inch-diameter hole through the duct. Each mixing fan only requires a ¾-inch diameter-hole. Two ½-inch-diameter holes are required to insert a soaker-hose sampler.
- TRAMS is versatile. The whip injectors and mixing fan blades can be customized to fit rectangular, circular, or oval ducts of different dimensions. Varying the CO_2 injection rate allows measurements of a very broad range of airflow rates.
- Installation is fast. The mixing fans and whip injectors are held in place on the duct by magnets. No mechanical fasteners are required.
- Measurement is fast and repeatable. Injection takes about 10 seconds; one measurement process takes minutes.
- Data processing is computer automated.

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Better Measurements of Carbon Aerosol Help Study Climate Effects

[Part 1 of this series, in the Spring 2004 issue of EETD News, *examined the contributions of Tihomir Novakov and his research group at Lawrence Berkeley National Laboratory (Berkeley Lab) measuring carbon aerosol particles in the atmosphere and elucidating the significance of these particles. Part 2 describes continuing research at Berkeley Lab to improve our understanding of carbon aerosol particles and our ability to measure their mass and light-absorbing effects.]*

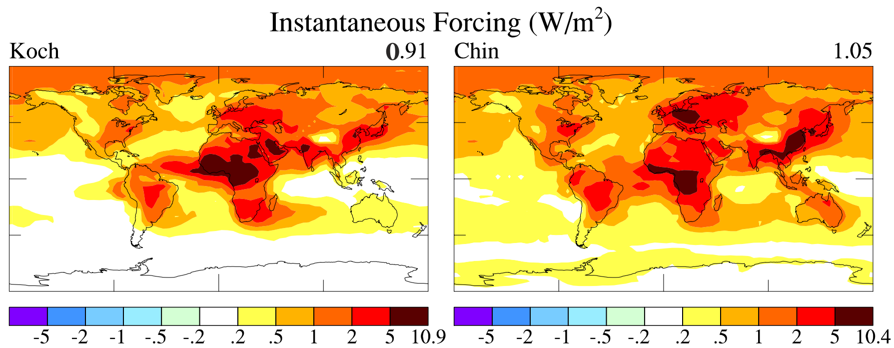

Figure 1. *Climate forcing by black carbon (BC) and organic carbon (OC), from AERONET data, with two different models for calculation. Forcing, in watts/m², is a measure of the additional power absorbed by the earth's atmosphere from the sun at a given moment, in this case because of the presence of BC from human sources. From AERONET data such as this, Makiko Sato, James Hansen, Novakov and other researchers inferred that black carbon in the atmosphere was two to four times higher than previously believed*

Now that researchers in the atmospheric sciences community have come to believe, thanks to the work of Berkeley Lab's Tihomir Novakov and his colleagues, that carbon particles play a significant role in the atmosphere, it is important to understand the history of these particles and to measure their concentrations with more accuracy than has been possible in the past. Among the discoveries in which Novakov and fellow researchers have recently participated is that black carbon (BC) may be contributing to climate change by absorbing the sun's heat and thus helping to warm the atmosphere.

In May 2003, Novakov, along with Makiko Sato, James Hansen, and seven other researchers at the National Aeronautics and Space Administration (NASA) Goddard Institute for Space Studies, published a paper inferring the global concentration of BC in the atmosphere based on data from the Aerosol Robotic Network (AERONET) of 250 sunphotometers, which measures the optical depth of the atmosphere around the world.

The researchers found that, to be consistent with AERONET data, the concentration of BC in the atmosphere had to be two to four times greater than climatologists believed (Figure 1). This higher concentration suggested that BC must be having a greater effect on climate change than previously thought; BC would contribute to climate change by increasing the amount of the sun's heat absorbed by the atmosphere. The news of this research attracted considerable attention from the media.

128 Years of Black Carbon

Working with colleagues Tom Kirchstetter, Jonathan Sinton, and Jayant Sathaye of Berkeley Lab, as well as Hansen, Sato, and V. Ramanathan of the Scripps Institution of Oceanography, Novakov has also documented historical changes in atmospheric BC concentrations from 1875 to the present in the six regions of the world that account for most of today's BC aerosol emissions: China, India, the former Soviet Union, Germany, the United Kingdom, and the United States. Using the historical record of coal and transportation fuel burning, the group estimated how much BC might have been emitted to the atmosphere. Calculations were based on emissions rates from today's power plants and combustion engines and assumptions of past emissions rates.

The group's preliminary estimate of historical atmospheric BC concentrations shows a large increase during the second half of the 20th century. BC concentrations increased rapidly during the late 1800s, leveled off during the first half of the 1900s, and then began to accelerate during the past 50 years (Figure 2). Industrialization in China and India contributed a substantial portion of this recent increase.

Climate scientists now are using the AERONET and historical data to improve computer models' representation of BC's effects on climate change.

Improvements in Aerosol Sampling

Researchers would like global atmospheric carbon measurements to be as accurate as possible so that computer models can accurately estimate BC's climate effects. Since 1999, Kirchstetter, a scientist in the Environmental Energy Technologies Division (EETD) who works with Novakov, has been honing the accuracy of current sampling methods for both BC and organic carbon (OC).

The usual way to measure the mass concentration of carbon particles in the air is to force air through a quartz filter for a period of time and then heat the filter to drive off volatile

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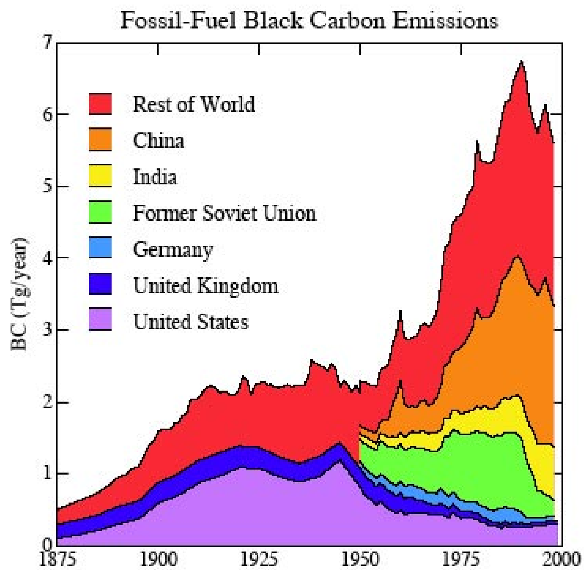

Figure 2*. Estimated fossil fuel black carbon emissions since 1875, in gigatons (billions of tons) per year*

organic compounds and combust the BC. Finally, the evolved carbon is oxidized over a catalyst to form carbon dioxide (CO_2), a gas that is easy to measure. "The evolved gas analysis [EGA] system we use for this purpose was developed and refined at Berkeley Lab," says Kirchstetter. The instrument (Figure 3) measures the amount of CO_2 released as the temperature rises, creating a thermogram, which shows the mass of the carbon in the sample and can be used to distinguish between black and organic carbon.

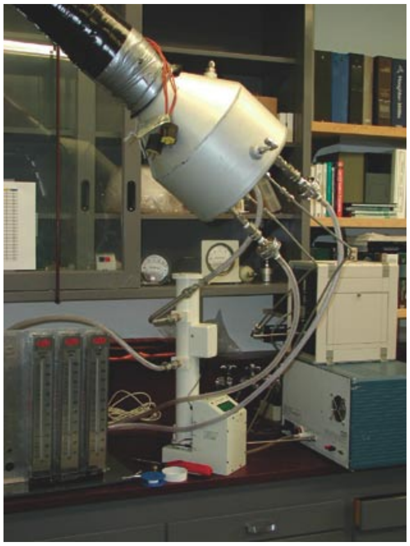

Figure 3*. The evolved gas analysis system (Photo courtesy Ted Gartner)*

Kirchstetter doesn't even have to leave the building to take a sample of Berkeley air because a stack from his lab connects to the roof where an air sampler is located (Figure 4). The equipment was built by Richard Schmidt, who has been a key member of Novakov's group since its beginnings in the 1970s. Kirchstetter notes that "Schmidt fabricates almost all of the instrumentation we use to do research."

"Measuring carbon aerosols in the air is a tricky business," Kirchstetter explains. "One problem is that the carbon content on the filter doesn't always reflect the carbon particle concentration in the atmosphere because of sampling artifacts. Filters adsorb gases, including organic carbon." Kirchstetter developed a simple method of correcting for adsorbed OC gas by putting a second filter behind the first in the EGA measurement setup. The second filter measures only OC gas in the air sample because carbon soot has been trapped in the first filter; the thermogram of the second filter can be subtracted from that of the first to increase the accuracy of the final measurement.

Figure 4*. The stack sampler (Photo courtesy Ted Gartner)*

Kirchstetter's method for correcting for OC gas adsorption has increased the accuracy of atmospheric carbon measurements, but there are still problems to solve. For example, different laboratories can measure the same air sample and get different results because of sampling and analytical artifacts other than OC gas adsorption. To address this problem, Kirchstetter and colleague Lara Gundel are now working with other labs to develop "more robust sampling and analytic procedures for black and organic carbon."

From Rooftop to High-altitude Sampling

Kirchstetter has participated in a variety of air-sampling experiments around the world in recent years.

In 2000, he joined a multinational group of scientists in the South African Regional Science Initiative (SAFARI) program and spent five weeks flying on a research aircraft, along with Peter Hobbs of the University of Washington, measuring carbon aerosols in the atmosphere. "We often saw smoke plumes from burning savannah," he says. "Some were prescribed burns; some were natural fires." SAFARI provided a wealth of data from southern Africa about the prevalence of atmospheric carbon particles from burning biomass.

Kirchstetter has also participated in the Indian Ocean Experiment, INDOEX, working with colleagues from the University of Puerto Rico to analyze samples from the Indian Ocean where pollutants drift in from the Indian subcontinent. Pollutants can have a larger effect on regional climate than on overall global climate; on the Asian continent, many regional-scale brown clouds are produced by burning of forests, diesel fuel, and coal. One such cloud drifts south from Asia over the Indian Ocean. The brown haze is implicated in regional climate effects such as intensified periods of drought and rainfall, as demonstrated in climate simulations by Surabi Menon, Kirchstetter's colleague in EETD's Atmospheric Sciences Department. Kirchstetter is one of a number of scientists working with V. Ramanathan of the Scripps Institution of Oceanography, analyzing samples for the Atmospheric Brown Cloud (ABC) project, which was established to examine the climate effects of these clouds.

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Better Measurements of Carbon Aerosol Help Study Climate Effects

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As part of the Mega Cities project, developed by Mario Molina of Massachusetts Institute of Technology, Kirchstetter will analyze air samples collected over large metropolitan areas, including Mexico City, to understand how aerosols and other pollutants in brown clouds affect large cities.

Organic Carbon—Contributing to Climate Change?

Researchers are now taking a close look at the OC component of carbon aerosols to determine whether, for example, differences between smoke from biomass burning and smoke from diesel fuel have implications for climate change. "In addition to the mass concentrations of these particles," says Kirchstetter, "we're studying their optical properties, so they can be represented realistically in climate models."

Recently, Kirchstetter has found evidence that OC from biomass burning ("wood smoke") behaves differently from that produced by diesel-fuel burning. Using a specially designed device, the multiple wavelength light transmission instrument (MULTI) built by Dick Schmidt, Kirchstetter and Novakov are studying a range of wavelengths of light and their absorption by OC from both wood smoke and diesel combustion. The MULTI consists of a group of light-emitting diodes (LEDs), each emitting a narrow region of the electromagnetic spectrum, and a detector (Figure 5). The MULTI incorporates elements of the aethalometer (another instrument for measuring BC, also developed at Berkeley Lab and described in Part 1 of this series) and commercial optical spectrometers. When a filter sample is placed between the LEDs and the detector, the MULTI produces a plot of the amount of light absorbed by the carbon aerosol in the filter at different wavelengths. Heating the filter removes the carbon aerosol. The sample can then be measured again and compared to the first results to show how the light absorption is affected by the presence of the carbon aerosol.

Figure 5. *The multiple wavelength light transmission instrument (MULTI) (Photo credit Ted Gartner)*

Kirchstetter has made numerous measurements with the MULTI, some of samples from his lab's roof sampler (representing ambient air in Berkeley), some of samples from the SAFARI project described above (mostly biomass smoke), and some of air drawn from the Caldecott Tunnel, a portion of Highway 24 heavily traveled by drivers in the San Francisco Bay Area (carbon aerosols in these samples are mainly from diesel smoke).

"Most climate models include black carbon as the only light-absorbing aerosol species," says Kirchstetter. "Organic carbon is assumed to be purely scattering, not absorbing." Although OC is not currently considered a contributor to global warming, "there is some indication that you can produce non-black carbon particles that are light-absorbing."

Kirchstetter and Novakov are studying the spectral dependence of aerosol light absorption, that is, how the absorption varies as a function of the light's wavelength. They found that the SAFARI samples (air affected by biomass burning), which contain a lot of OC, exhibit a spectral dependence different from that of Caldecott Tunnel samples (air with diesel particles), which contain a lot of BC. This result suggested that biomass-burning samples contain material other than BC particles that absorbs some of the sun's heat; the researchers suspected OC, and, to investigate further, used a strong solvent and extracted OC from their samples. Once they had extracted OC from the SAFARI samples, Kirchstetter and Novakov expected that those samples would behave more like the ambient air and tunnel samples, and that is exactly what they found. Their conclusion: "Biomass smoke samples actually have an organic component that absorbs some light…More generally, under certain combustion conditions, emitted organic carbon particles may contribute to light absorption," says Kirchstetter. This means that OC may be having an effect on climate change that is not accounted for in current computer models – a new and fruitful research area.

With these results, Kirchstetter is now working with EETD's Doug Black to combine the MULTI and the EGA method. The researchers plan to develop a field-deployable apparatus that would include two instruments: one to measure mass concentration of carbon aerosols and the other to measure the particles' light-absorbing effect. The two scientists will soon begin a study of "coated"

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Better Measurements of Carbon Aerosol Help Study Climate Effects

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particles, BC particles that have mixed with other chemicals in the atmosphere and in the process acquired an additional layer of material. These mixed particles may have an effect on climate change that is different from the sum of their components. The effect of mixing or coating currently is poorly understood.

Kirchstetter will also be returning to the Caldecott Tunnel this summer to make new measurements of pollutant emissions. He made his original measurements when gasoline in California still contained the additive methyl tertiary-butyl ether (MTBE), which has since been removed from California's gasoline because of undesirable environmental effects. With new measurements, Kirchstetter and colleagues Rob Harley (from the University of California Berkeley) and Tony Strawa (from NASA Ames Research Center) hope to understand whether the change in gasoline formulation has altered automotive pollutant emissions for better or for worse.

—*Allan Chen*

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This research was supported by the Department of Energy's Office of Science.

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TRAMS: A New Tracer Gas Airflow Measurement System

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Test Results

Figure 3 shows the results of 32 laboratory tests of TRAMS measuring airflows in straight rectangular ducts, with and without a Tee junction upstream of the measurement section. The reference flow meter has a rated accuracy of 0.5 percent. These results indicate that the accuracy of TRAMS is better than two percent.

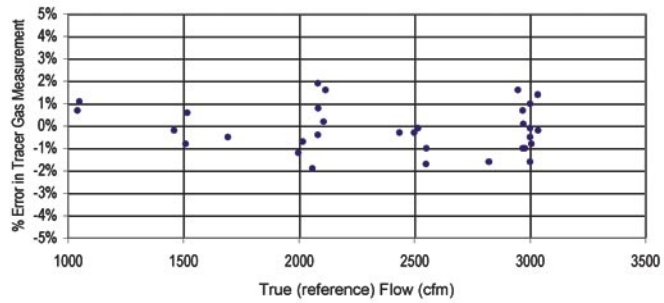

Figure 3. *TRAMS' accuracy in a laboratory study*

—*Duo Wang*

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Environmental Energy Technologies Division News

Published Quarterly

Vol. 5, No. 3

This work was supported by the U.S. Department of Energy under Contract No. DE-AC-03-76SF00098.

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LBNL/PUB-821 Vol. 5. No. 3, Summer 2004

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