Building Data Visualization

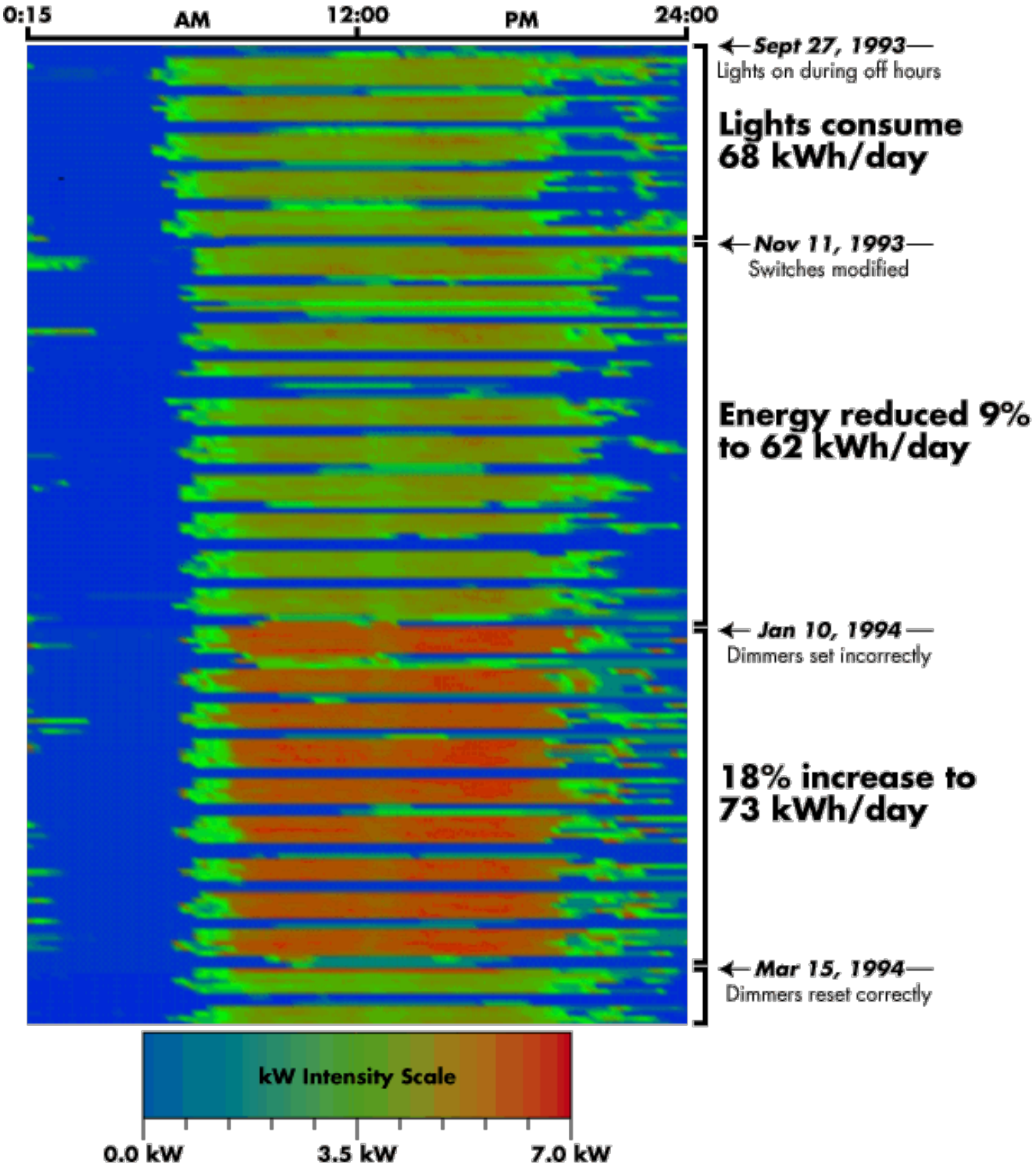

Figure 1: Contour plot showing the various operating stages of occupancy sensors described in the case study.

Data visualization for buildings is the display of a rich set of variables and parameters that managers can use to verify the energy savings of energy-efficient technology and identify malfunctions in building equipment or problems with operating strategies. Effective data visualization depends on having graphic presentation formats that reveal the phenomena relevant to the building's performance. A research project at the Center for Building Science is aimed at developing data visualization techniques for improved building management. Buildings with energy management control systems as well as dedicated monitoring equipment in the San Francisco Bay Area provided the data for case studies of data visualization described here and in a detailed LBNL report available from the authors.

Today, engineering estimates of energy use and savings are the basis of most energy-efficient building design and retrofit projects. Unfortunately, in the field, these buildings often perform very differently from design estimates. Measured data can help verify energy savings, illuminate control and operational problems in a building, and test the accuracy of predictive methods. Such data are increasingly necessary in energy performance contracting, utility DSM program evaluation, and other activities where regulatory requirements or financial contracts require actual energy performance and costs to be documented.

Analysts now have considerable experience with the use of measured building energy and environmental data. However, the information is often in the form of point estimates, such as total annual or monthly energy use. In recent years, data collection has tended toward increasing disaggregation into shorter timesteps and specific end uses. The rapid development of data- acquisition technology, computer workstations, and graphics software has allowed detailed building energy data to be collected and visualized in new ways. This offers various benefits:

- identifying anomalous or suspect values (e.g., from faulty sensors)
- identifying otherwise undetected malfunctioning systems that are jeopardizing energy savings, equipment life, safety, or comfort
- identifying poorly commissioned systems, where actual performance is inferior to that anticipated at the design stage
- revealing desired or undesired correlations among multiple variables (e.g., mechanical systems, weather conditions, and operating factors)

- identifying the most effective graphical display and the minimum data timestep (minute-by-minute, hourly, daily, weekly, or monthly) required to resolve critical phenomena

The following is a brief description of a case study that illustrates how data visualization can help building managers detect operating problems and optimize their facilities' energy use.

Case study: Recommissioning a Lighting System. Figure 1 shows a "contour plot" representation of energy consumed by a bank of lights in 1,000 m2 (10,000 ft^2) of office space. Although somewhat difficult to read in this duotone version, the plot clearly indicates the on/off status of the lights and the energy consumed. This plot facilitated the detection of two problems. First, during the late evenings between 9/27/93 and 11/11/93, the lights were used more than would be expected. Building managers determined that this was due to the tripping of occupancy sensors by a security guard. As a result, the building owner installed manual-on/automatic-off switches. The second problem can be seen in the 18% increase in energy use after 1/10/94. On that day, an electrician accidentally reset the centrally controlled dimmable ballasts to their maximum settings. The increased light levels were not noticed by the building's occupants but were easily detected and corrected using the information provided by the contour plot shown here.

Currently, the project team is using commercial software to analyze monitored building data on the University of California, Berkeley, campus. The results are recorded in a specially designed database. Custom software developed in this project is being adapted for use in the Building Life Cycle Information System, BLISS (CBS News, Summer 1995). Members of the BLISS project will use data collected from Berkeley's Soda Hall to develop and calibrate a real-time operations model of a chiller, which will be added to the DOE-2 building energy simulation model.

(For further case studies and full-color images, see the Building Data Visualization for Diagnostics, Operator Feedback, and Performance Optimization by Steven Meyers, Evan Mills, and Allan Chen)

—Steven Meyers and Allan Chen

Please contact the authors to obtain a report (LBL-36704) with further discussion of data visualization and more examples of case studies.

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This work is funded by the Assistant Secretary for Energy Efficiency and Renewable Energy, Federal Energy Management Program of the U.S. Department of Energy, and by the University of California Energy Institute.

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News From the D.C. Office

Greenhouse Gas Mitigation Workshops

LBNL brought technical training to four continents this summer with a series of regional greenhouse gas mitigation workshops. As part of LBNL's continued work on the U.S. Country Studies Program (USCSP), staff members of the Energy Analysis Program from Washington, D.C. and Berkeley worked together to put on workshops in Warsaw, Poland; Cancun, Mexico; Arusha, Tanzania; and Seoul, Korea.

LBNL began working with USCSP more than a year and a half ago, when it was awarded the contract to provide mitigation assistance to some 35 countries. The Program grew out of the U.S.'s commitment to help developing and transitional countries address climate-change issues— specifically to examine how to reduce greenhouse gas emissions. The USCSP's work is organized according to guidelines established in the United Nations Framework Convention on Climate Change (FCCC), which was created as a result of the 1992 "Earth Summit" in Rio de Janeiro. An interagency management team brought together by the White House oversees the program. The Country Studies goal is to provide assistance in four areas: emission inventories, vulnerability and adaptation assessments, mitigation assessments, and assistance in forming and evaluating strategies for mitigation and adaptation.

In the past, LBNL provided technical mitigation assistance to countries individually and twice assembled research team members in Berkeley for training. This summer's workshops brought participants together to compare and discuss regional results and issues. Each workshop program consisted of three to four days of presentation and discussion in energy and nonenergy groups.

The first workshop, held June 13-16 in Warsaw, set the tone for those that followed. Co-sponsored by the Organization for Economic Cooperation and Development (OECD), it brought together more than 90 scientific and policy experts from 23 East European countries. The workshop provided a forum for discussing the methodology and some preliminary results of the participants' own mitigation assessments. Papers presented there were published in a hardbound volume of proceedings.

The second workshop was held in Cancun, July 10-13 for Latin American countries. Co-sponsored by the Instituto Nacional de Ecologia (INE) and the Organizacion Latino Americana de Energia (OLADE), it brought together about 60 participants from 13 countries and also generated a book of proceedings. The African workshop was held August 28-30, and the Asian one September 25-28.

This series of four regional workshops marks the midpoint of LBNL's technical assistance. Once the technical assistance phase is complete, LBNL will publish a synthesis report, due in mid-1996. LBNL will also assist USCSP in the next phase, which will help countries use the results of their studies to prepare greenhouse gas mitigation plans and conduct technology assessments. Staff in Washington and Berkeley may again be called on to assist.

LBNL staff leading the four workshops were:

- WARSAW: Jayant Sathaye, Steve Meyers, and Mirka della Cava
- CANCUN: Steve Wiel and Beth Goldberg
- ARUSHA: Steve Wiel, Willy Makundi, Steve Meyers, and Mirka della Cava
- SEOUL: Jayant Sathaye and Beth Goldberg

They were assisted by Antonio del Monaco, John-David Hague, Emma Kahn, and Chris Ganson.

—Emma Kahn

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This work is supported by the U.S. Country Studies Management Team (a thirteen-agency task force of the U.S. government)

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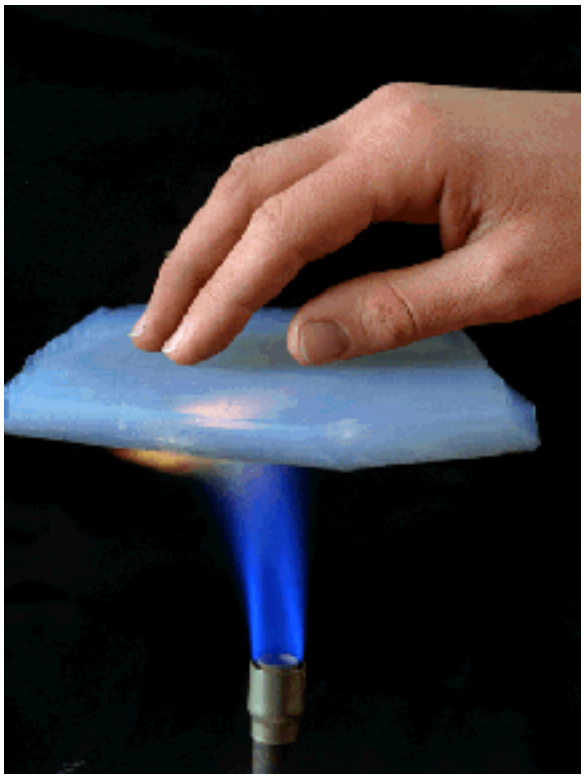
Aerogel: Energy-Efficient Material for Buildings

To Aerogels web site



A demonstration of an aerogel's exceptional insulating properties

An ounce of aerogel has the surface area of 10 football fields, and this is only one of its interesting properties. Aerogel has great potential in a wide range of applications that include energy-efficient insulation and windows, acoustics, gas-phase catalysis, battery technology and microelectronics. The Microstructure Materials Group of LBNL's Energy Conversion and Storage Program has been studying both the basic properties of aerogel and techniques to refine desirable qualities like transparency and insulating efficiency. Another

goal of the group is making the manufacture of aerogel safer and less expensive.

As implied by the name, aerogel is mostly air. It is the lightest existing solid material, and it can have a surface area as high as 1,000 m2 per gram. Aerogel is one of the few existing materials that is both transparent and porous. It can be formed into almost any useful shape and makes an excellent insulator. Although silica aerogel is the most familiar form, metal oxides such as iron and tin oxide, organic polymers, natural gels, and carbon can all form aerogels. Discovered more than 60 years ago, they are being developed in the Microstructure Materials Group with an eye to commercial application.

Steven Kistler, at what is now the University of the Pacific, in Stockton, California, first experimented with aerogels in the 1930s. He proved experimentally that the more familiar liquid-based gels or jellies were an open solid network of cells permeated by liquid. Kistler made the first aerogel by soaking a water-based gel in alcohol to replace the water. Then he heated the alcohol and gel in a closed container to a high temperature and pressure (80 atmospheres and 240°C) and slowly depressurized the vessel. This allowed the alcohol, now a vapor, to escape, leaving an air-filled cellular matrix.

Today, researchers typically prepare metal oxide aerogels by reacting metal alkoxide with water to form an alcosol, a suspension of metal oxide particles in alcohol that link together to form an alcogel (alcohol-permeated gel). The alcogel is then dried at high temperature and pressure to produce aerogel.

The Microstructure Materials Group developed a process for producing aerogel at lower temperature and pressure by substituting liquid carbon dioxide for the alcohol in the gel under pressure, then drying the aerogel with carbon dioxide at 40°C and 70 atmospheres—considerably reducing the risk of explosion and fire compared to the high-pressure alcohol process. The new method also decreases the energy use and manufacturing time thereby lowering the costs.

Aerogel's primary building-related application is as a transparent or high-performance thermal insulator. An obvious choice for superinsulating windows, skylights, solar collector covers, and specialty windows, aerogels are transparent because their microstructure is small (average pore size is 10 to 20 nanometers) compared to the wavelength of light (400 to 700 nanometers). Their slightly hazy blue appearance is a deviation from transparency that is caused by the occasional appearance of large pores, a happenstance revealed by the Microstructure Materials Group's light scattering and transmission electron

microscope studies. Thus, current research to improve aerogel clarity at LBNL is focused on decreasing the number of larger pores.

Arlon Hunt studies a sample using a light scattering instrument.

Aerogels are efficient thermal insulators as well. Silica aerogel has a higher thermal resistance than the polyurethane foams that are widely used in refrigerators, boilers and building insulation. Since these foams are blown with ozone-depleting CFCs, aerogels could be an excellent CFC-free alternative. Aerogels in a partial vacuum are even better insulators, because removing most of the air from their pores eliminates half to two-thirds of the material's thermal conductivity (the portion due to gas conduction). Silica aerogel in a 90% vacuum, which is simply and inexpensively produced, has a thermal resistance of R-20/in. Thus, a one-inch-thick aerogel window has the same thermal resistance as a window with ten double panes of glass. LBNL researchers have improved their performance to R-32/inch by adding carbon, to absorb infrared radiation in the material, another mechanism of heat transfer. Carbon-doped aerogels are perfect candidates for opaque insulators such as those used in refrigerators and pipes.

Current LBNL research is focused on developing new nanocomposite materials based on chemical vapor infiltration and reaction of gases in the aerogel. The resulting materials may have a wide range of applications in electronics, optics, and sensors. A cooperative research and development agreement with Aerojet Corp. will transfer the production methods into the commercial sector and refine the current aerogel process for large-scale production. The group is also

working with Maytag on refrigerator insulation application, with General Motors and Bentley on automotive insulation, and with Boeing on acoustic and thermal insulation.

—Arlon Hunt and Allan Chen

To Aerogels web site

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This work is supported by DOE's Office of Industrial Technologies and the Advanced Research Project Agency's Technology Reinvestment Project.

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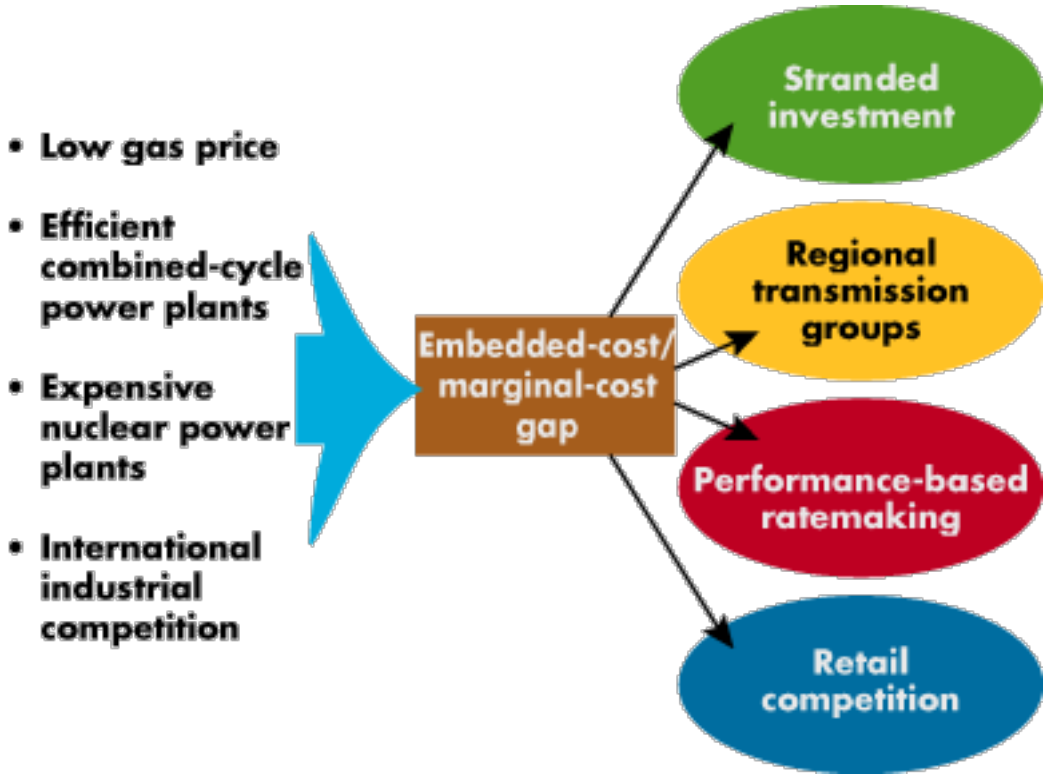
Center Research ... Supports Electric Utility Restructuring



Winds of change in the U.S. power sector: factors listed in the left column have created a gap between the prices utilities must charge to recover their embedded costs and the lower rates they would have to charge in a competitive environment. Possible responses to these pressures are listed to the right.

The electricity industry in the U.S. is being dramatically restructured by state regulatory commissions and the Federal Energy Regulatory Commission. Efforts are underway to create a wholesale market for electricity, with wholesale prices to distributing utility companies no longer being regulated. Discussions in several states and at the FERC are aimed at revising the regulation of the structure, operation, and pricing of the electricity transmission grid to make it available on comparable terms to all generators and distributors— and perhaps individual customers. LBNL researchers studying

this restructuring have shown in general that cost reductions are achievable by modifying the way we regulate electric utilities, that such cost savings will likely come slowly, and that current social goals can be maintained in a competitive, market-based electricity industry with an overall benefit to our country.

Research on restructuring in the Center, largely conducted under DOE's Integrated Resource Planning Program, is spread throughout the Energy Analysis Program. One such project has shown that commercial lighting demand-side management (DSM) programs are economically justified (CBS News, Summer 1994).

Another project focuses on the efficiency of electricity generation and transmission. The 1992 U.S. Energy Policy Act reflects a debate initiated by bond rating agencies on whether long-term power purchase contracts between nonutility generators (NUGs) and utilities are the equivalent of utilities debt and therefore raise the cost of capital to the purchaser, or do these contracts reduce risk to the utilities. Ed Kahn, Steve Stoft, and Tim Belden have approached these questions from the perspective of the equity markets. If NUG contracts really are equivalent to debt, then they raise the risk to the firm and this should be observable in the equity market. The evidence does not support the hypothesis that NUG debt translates to utility debt. Evidence does suggest that utility construction raises the cost of capital more than NUG purchases do. Also, private power prices appear to be coming down. These findings support arguments for the unregulated wholesale pricing of electricity.

DSM can be treated as a "supply resource" and become a competitor in an unregulated or less regulated wholesale supply market. Since 1987, about 35 U.S. utilities have signed long-term contracts with developers of DSM resources (typically energy service companies) to provide a quantity of demand and energy savings at specified prices. DSM bidding programs account for only a small portion of the savings (~5%) achieved by utility DSM efforts nationally, but interest continues to increase. Charles Goldman and Suzie Kito have completed the first comprehensive study of 18 DSM bidding programs. The cost of ten of these programs ranged from 5.4 to 8¢/kWh. They compared the allocation of risks among ratepayers, utility shareholders, DSM developers, and participating or host customers in a prototypical utility rebate program and a DSM bidding program and found that utilities use various contractual mechanisms to mitigate the risks of DSM resources to ratepayers. These risk-mitigation options (including various types of security deposits, damage and penalty provisions, and "regulatory out" and "buy out" clauses) protect

ratepayers quite well in situations in which projects fail to develop or energy savings deteriorate over the contract term. Thus, from a policy perspective, DSM bidding programs can have an important role in a restructured industry because they are performance- based— utilities typically pay only for energy savings that are verified over relatively long contract terms.

Alan Comnes and Steve Stoft are investigating the characteristics of new regulatory rate-setting mechanisms as alternatives to total price deregulation. Performance-based ratemaking (PBR), the primary challenger to traditional cost-of-service ratemaking, strengthens financial incentives to improve rates, costs, or other aspects of performance. Comnes reviewed nine proposals for PBR made by "early adopting" gas local distribution companies and found that PBR is most often considered a regulatory alternative when a utility faces competition and restructuring in one or more of its business segments. The most common strategy employed by PBR mechanisms is to weaken the link between a utility's regulated prices and its costs and to rely more on market indicators. Despite its positive benefits found in this research, PBR for energy utilities is not universally accepted as superior to traditional rate-of-return regulation. Future attempts by utilities to use this relatively new approach are likely to prove beneficial.

These research projects and a number of others in the Energy Analysis Program are providing a more solid basis for economically efficient electricity sector restructuring.

—Steve Wiel

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VOC Exposure Metrics ... and "Sick Building Syndrome"

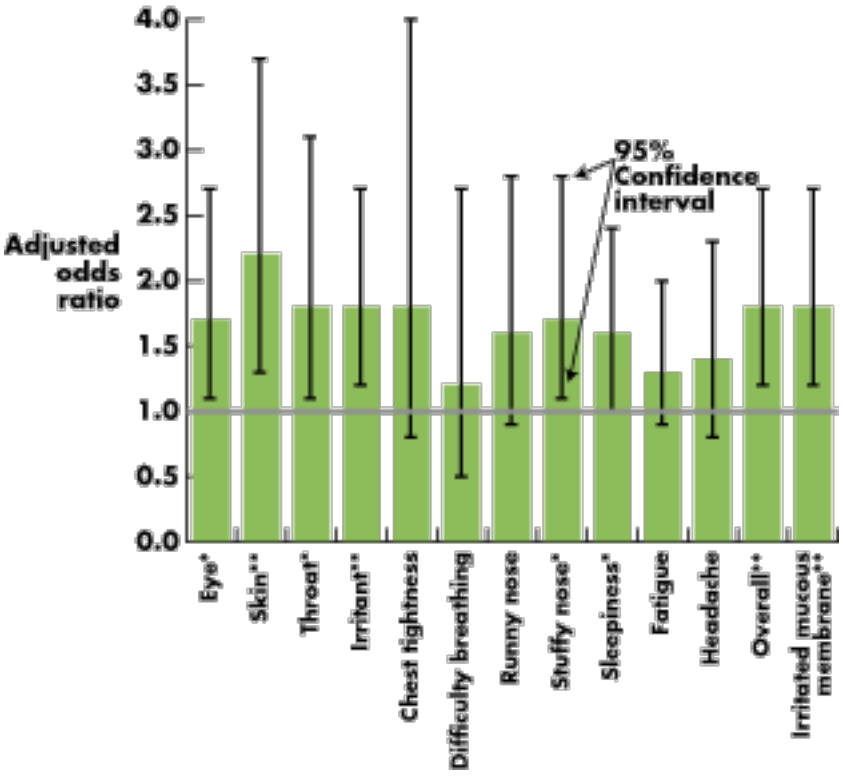

Figure1: The elevated odds ratios (above unity) in this figure suggest that exposures to VOCs from water-based points and solvents are associated with a variety of sick building symptions (* indicates the OR is significant at $p < 0.05$; ** for $p < 0.01$).

The indoors is often regarded as safe haven from problems associated with outdoor air pollution, but a growing number of reports have suggested that exposures in indoor environments may lead to health problems. One area in which evidence has been accumulating is the relationship between working in office buildings (as opposed to industrial exposure conditions) and a variety of health effects, such as eye, nose, and throat irritation and dry, itchy skin. Such symptoms are often considered part of "sick building syndrome" (SBS), which is a complex of symptoms that may arise while inside a building (and which

may improve or disappear upon leaving the building). High prevalences of these symptoms have been reported from various epidemiological investigations of SBS, but the exact nature of the chemical and physical characteristics of the indoor environments is not known, nor is the cause-and-effect relationship between the exposures and these health effects understood.

Among the suspected causes are volatile organic compounds (VOCs). Indoor air typically contains between 30 and 100 VOC species at concentrations that are readily measurable. Exposures to individual VOCs— typically at high concentrations— have been linked with sensory, pulmonary, and neurologic responses. However, in office buildings, occupants are often exposed to mixtures of individual VOCs, each at low concentration. Some researchers have hypothesized that high total concentrations of VOCs are a causative factor of SBS symptoms, and thus total VOC concentration (TVOC) can be used as an exposure metric that is related to symptoms. However, few significant associations have been found between TVOC concentrations and SBS symptoms in studies in buildings.

Indoor Environment Program researchers* have recently developed new VOC exposure metrics that account for the differences in response to the various VOCs and in the VOC sources. The response is based on the "potency" of individual VOCs to elicit symptoms, estimated from available irritancy measurements. Because the human irritancy of so few compounds has been tested, we based our potency estimates on available animal bioassays or, when no data were available, on properties of similar compounds. The most irritating VOCs were then selected and used in a principal component analysis, which yielded "clusters" of VOCs with concentrations that increase or decrease together because the compounds within a cluster have a common dominant source.

The California Healthy Buildings Study (CHBS), an investigation recently completed by LBNL scientists in 12 office buildings in or near San Francisco, provided data on indoor VOC concentrations (see article in CBS News, Spring 1994). Based on these data, we identified four clusters of VOCs associated with specific sources: motor vehicle emissions, building materials, carpet/building materials, and water-based paints and solvents, using principal component analysis. These clusters represent groups of both measured VOCs and those with the same sources that have not been measured because of limitations in technology. Both the measured and unmeasured VOCs in each cluster may cause observed symptoms. Principal component analysis iteratively develops coefficients for each VOC that reflect the association (positive or negative) of

that VOC with the source. The principal components representing each cluster are composed of the sum of the original VOC concentrations multiplied by the individual VOC principal component coefficient; these sums range from roughly -3 to 3.

The new VOC exposure metrics were applied to the CHBS data set. We used SBS symptom data reported on a written questionnaire by 517 office workers who were in close proximity to 22 sites where 39 individual VOCs were measured. As a result, we developed a set of data associating the VOC clusters with SBS symptoms that could then be examined to determine which associations were significant statistically.

The method used in this examination was based on an odds ratio (OR), which represents the odds of experiencing a symptom (versus the odds of not experiencing a symptom) given increased VOC exposure. The principal components representative of VOC sources are used as independent variables in the prediction of SBS symptom outcomes in a logistic regression analysis. As with linear regression analysis, this technique describes the relationship between an outcome and a set of independent or predictor variables. However, the results of a logistic regression are binary. That is, they predict the presence or absence of a symptom. An odds ratio is calculated for each independent variable based on the regression analysis. An OR of 1.0 indicates that the odds of experiencing a symptom do not vary with VOC exposure level; conversely, an OR greater than 1.0 indicates that VOC exposure does affect symptom outcome. Those ORs with confidence intervals (error bars) that exclude 1.0 are statistically significant.

As seen in Figure 1, after adjusting for potentially confounding influences, the source identified (using principal component analysis) as water-based paints and solvents was associated with several SBS symptoms, including dermal (OR=2.2, 95% Confidence Interval 1.3-3.7) and eye (OR=1.7, 95% CI 1.1- 2.7) irritation. The ORs represent the increased odds of experiencing the symptoms, given a one-unit change in the principal component (where the range is ± 3). The more typical TVOC exposure metric used in prior analyses was not useful in symptom prediction in the adjusted model. Also not useful were metrics that took into account potency but did not rely on principal component analysis to identify clusters of VOCs.

As demonstrated by this work, sophisticated methods are needed to understand the associations between health effects and exposure to complex mixtures.

These new VOC exposure metrics appear to have significant potential for helping identify causes of and potential solutions for SBS.

—JoAnn Ten Brinke

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Fall 1995
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Energy Currents

Survey Result

Our thanks to all of you who responded to our reader survey. We were pleased that many of you find this a useful publication. Your opinions will help us improve it further.

The CBS News' readers include a variety of professions. 17% of respondents were consultants, 15% were engineers, 11% were teachers, 11% were scientists, 10% were program managers. The remainder included contractors, designers, marketing professionals policy analysts, journalists and others. Ranked according to highest response first, the majority of readers work in education, various levels of government, utilities, non-profit organizations, and a variety of private concerns.

A surprisingly large number, 52% of the respondents, are Internet users and 23% have browsed the World Wide Web. 8% have browsed the Center's Web site (and we invite more of you to do the same). 28% have contacted the Center about its work.

82% felt that the level of writing is "just right," and 81% felt the same about article length. 95% found the graphics to be "very clear," or "moderately clear." 80% of survey respondents have saved issues or articles. We continue to welcome your comments and suggestions.

Awards

Dr. Arthur Rosenfeld, former director of the Center for Building Science, and now Senior Advisor to the Secretary for Energy Efficiency and Renewable Energy, DOE, was honored for his contributions to energy efficiency along with two others at a Washington D.C. awards dinner of the Alliance to Save Energy in June. The Alliance was formed by Senators Charles Percy and Hubert Humphrey in 1977 to bring together the public and private sectors for the purpose of promoting cost-effective energy efficiency. The other honorees were Senator Mark Hatfield and the 3M Corporation.

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A-Team Report

We are pleased to introduce a new department to CBS News. In each issue, you will find a brief update on projects being conducted by our new Applications Team.

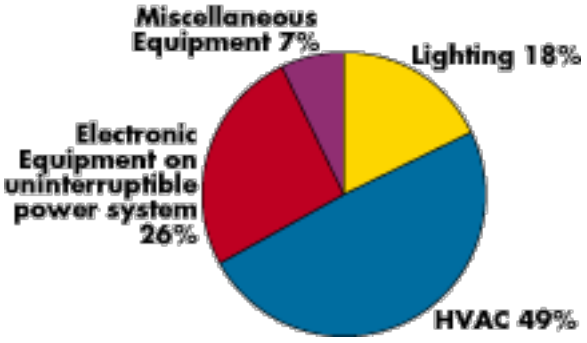
The Houston air traffic control tower

The A-Team has completed the first phase of work to help the Federal Aviation Administration become more energy-efficient (CBS News, Fall 1994). Phase one includes a detailed energy audit of an example of each type of facility in the FAA building stock, located in the Houston metropolitan region.

- Air route traffic control center
- Terminal radar approach control
- Automated flight service station
- Air traffic control tower (commercial airport)
- Air traffic control tower (private airport)

- Air surveillance radar
- Air route surveillance radar

The team has identified significant potential energy savings from energy-efficiency measures, including HVAC, control, and lighting upgrades. The combined energy cost-reduction potential from these recommendations exceeds 20%. A-Team project members have proposed retrofit projects worth $1.3 million with an average payback period of seven years. It should be noted that these upgrades are limited to energy use by noncritical loads- those not involved with the primary mission of the FAA (such as computer and radar systems). Below is a typical energy end-use pie chart for a Houston-area facility.



Electricity balance: Houston tower

Phase two of the work for the FAA has begun with an energy audit of the Seattle air route traffic control center. This phase will involve research and development teams at LBNL, whose members will build a baseline computer simulation model of the Center. This model, plus others we expect to do in the future, will allow priorities to be set on future energy audits that contractors will perform on FAA buildings during the next ten years. The A-Team also provided design assistance recently for a new air traffic control tower in Grand Junction, Colorado.

—Geoffrey Bell

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This work is supported by the Federal Aviation Administration.