Twenty Years of Lighting Research

For two decades, the Center for Building Science has been a leader in the energy-efficient lighting area, helping the U.S. chip away at its $38 billion annual lighting energy bill. The cost of global lighting energy use is approximately four times as great.

The Center's expertise spans the development and application of efficient lighting systems and technologies, energy policies, demand forecasting, utility program evaluation, training, design software, demonstration projects, and a host of international themes.

Research and Development

Since the late 1970s, the Center has worked with the lighting industry to develop and commercialize new technologies ranging from electronic ballasts to higher-performance compact fluorescent and sulfur lamps. Facilities in our lighting laboratory, including the goniophotometer and luminaire thermal performance instrumentation, support the development of new products, such as efficient infrared-halogen A-lamp substitutes for traditional incandescents, light guides, fiber optics, high-efficiency torchiere fixtures, (Fall 1996, p. 6) high-performance uplights, and lighting controls. Complementing the electric lighting systems work, Center researchers are also involved in a host of daylighting projects and related advanced window R&D (Winter 1995, p.6; Spring 1995, p.5; Summer 1995, p.4). We also consider the human dimensions of lighting as they pertain to the design of light sources and architectural applications. Center staff serve on numerous committees in the Illuminating Engineering Society, the International Commission on Illumination, and other professional organizations.

Market Transformation

The fruits of our lighting R&D efforts often give rise to new projects focused on large-scale deployment of new efficient lighting solutions. Current laboratory prototypes of efficient torchiere lights (Fall 1996, p.6) have led to a new partnership between large fixture and lamp manufacturers to produce these

at a commercial scale. Other projects focus on implementing efficient lighting in hotels, and assisting the Department of Defense and other large buyers in procuring energy-efficient A-lamp replacement technologies.

Lighting Design and Energy Calculation Tools

Several computer tools for lighting simulations and energy analysis have been developed at the Center. These include the photorealistic RADIANCE lighting design software, LEAR (Lighting Energy Analysis for Retrofits) for calculating energy and light output from commercially available lamps, DOE-2 for estimating lighting energy use in whole building simulations, and Superlite for quantifying daylight distributions in indoor environments.

Energy and Economic Analysis

Two models co-developed by the Center estimate the potential impacts of efficient lighting technologies on a national scale: COMMEND (Commercial End Use Forecasting Model) and REM (Residential Energy Model). Detailed end-use data from many sources has been gathered and synthesized for conducting a detailed assessment of lighting conservation potential in the U.S. Other projects include a comprehensive analysis of the impacts of lighting standards in the U.S. for particular efficiency options, such as high-intensity discharge lighting (Spring 1995, p.5). Researchers in the Database on Energy Efficiency Programs have evaluated the largest nonresidential lighting utility programs in the U.S. and validated their cost-effectiveness compared to new electrical energy supply (Summer 1994, p.7).

The International Dimension

Center staff have worked to promote lighting efficiency in other countries. In Mexico and India, they provided technical support for CFL (compact fluorescent lamp) market development projects. In the Netherlands they developed a lighting demand forecasting tool. The Center also recently published an assessment of the lighting market and efficiency potential in China. The Center helps organize the biannual Right Light conference, which brings together 250 people from 40 countries to discuss all aspects of energy-efficient lighting.

Information Outreach and Demonstration Projects

Developing information tools and demonstration projects to promote the use of efficient lighting systems has long been an important focus of the Center's lighting-related activities. The Center staff co-authored the 300-page Lighting Design Guidelines, collaborated with industry in workshops to help accelerate the commercialization of technologies such as dedicated fixtures for CLFs, and are developing an interactive residential energy analysis Web site that will address lighting and other end uses (Summer 1996, p.1).

The Center's Applications Team and the Federal Energy Management Program have conducted demonstration programs that include a lighting renovation and design project for the White House (Summer 1994, p.1); audits and retrofit studies for government agencies such as the Federal Aviation Administration (Fall 1995, p.8); lighting design for the 1996 Olympics; and a major lighting-controls demonstration project at the San Francisco Federal Building (see page 4). We have even practiced what we preach by retrofitting our own building to achieve more than 90% lighting energy savings (Summer 1994, p.5).

The U.S. Department of Energy has been our primary source of support for the accomplishments outlined in this article. The Center is continuing its 20-year tradition of conducting innovative lighting research and field applications for a wide variety of clients. We invite potential partners to call us and discuss how we might build on our track record and cooperate to develop new projects.

—Evan Mills & Nathan Martin

For a more detailed description of lighting projects and capabilities at the Center, see the Lighting Excellence Web site.

CBS Newsletter
Winter 1997
pg. 3

News From the D.C. Office

Efficient Office Equipment: Update and a Look Ahead

An extended version of this article is available here.

We are now well aware of the large amount of energy consumed by "plug-in loads" such as personal computers (PCs) and other office electronics. Office equipment is often cited as the fastest-growing end-use of electricity in the fastest-growing sector of demand (commercial buildings). According to Dataquest figures, world growth of PCs will average 14 to 15 percent per year through 1999. Only ten years ago, office equipment was not even part of the "map" of non-residential energy end-uses. There were virtually no data on office equipment energy use, nor an awareness of the substantial energy savings available-primarily through automatic switching to a low-power "sleep" mode whenever equipment is connected but not in use.

Thanks in part to a decade of research led by staff in the Center's Energy Analysis Program, the situation is dramatically different. Office equipment is a well-documented end-use in the commercial sector. Important energy efficiency programs in the U.S. and other countries, notably the ENERGY STAR® label (sponsored by the U.S. Environmental Protection Agency and DOE), focuses attention on this sector. The ENERGY STAR program promotes

the purchase of computers, monitors, printers, copiers, and faxes that automatically switch to a low-power mode (generally 30 W or less) after a pre-set period of inactivity.

Researchers at the Center and the Environmental Energy Technologies Division's Washington D.C. Projects Office continue to provide important leadership in this area. For example, a recent, widely publicized LBNL report* on the efficiency of office equipment found that EPA/DOE's ENERGY STAR program had the potential to save businesses and consumers more than $1 billion/year in electricity costs-provided that the power-management controls are properly enabled by the manufacturer and user, and are compatible with other hardware and software in our increasingly interconnected office systems.

Center researchers have compiled field-monitored results of actual savings and user experience with power-managed office equipment. Their key finding is that a relatively small fraction (about 15 %) of those computers and monitors with the software to automatically power-down are actually enabled to do so. Further efforts are needed with office equipment-as with many other energy-efficient technologies-to properly install, "commission," and educate users of ENERGY STAR products. This is the only way to assure that this equipment produces reliable, long-term energy savings and continues to satisfy users' needs. As a result of this finding, we have developed an extensive guide that explains how power management features work in PCs and monitors and how to use them in both stand-alone and network environments. The guide, intended for use by computer support personnel including MIS staff and LAN administrators, will be available later this year at both the Center's and EPA's World Wide Web sites.

Another project in the early stages is the monitoring and evaluation of savings in energy and paper from ENERGY STAR copiers. This work will evaluate energy savings from low-power modes, the auto-off feature that turns off the machines at night, and program features to increase duplexing rates. At the D.C. Projects Office, an effort is underway to develop a user's guide for copier features like automatic duplexing and weekly timers. All of the private sector partners in the ENERGY STAR copier effort will receive this "copier tool kit," which will include fact sheets to help them educate their customers, and a guide to train their own sales representatives and service technicians who work with copiers. The kit will also have general marketing materials such as newsletter articles, media releases and case studies.

—Jeffrey Harris, Mary Ann Piette, Jon Koomey, Bruce Nordman, Alison Watkins

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CBS Newsletter
Winter 1997
pg. 4

Hammer Award Honors a Federal Building's Energy-Efficient Retrofit

Figure 1: Each floor of the 21-story Phillip Burton Federal Office Building in San Francisco is more than 60,000 square feet. The lighting controls testbed occupies the third, fourth and fifth floors.

Vice President Al Gore's National Performance Review has given a Hammer Award to a team of private and public entities, including several Center researchers. The team is working to turn San Francisco's Federal Building at 450 Golden Gate Avenue into a showcase of energy-efficient technologies that could cut the federal government's annual energy bill by a billion dollars. The Hammer Award recognizes teams of federal, state, and local employees and private citizens who have made government more efficient and effective.

A study of potential savings by the team's energy modeling specialists found that the new technology and control system could reduce the Philip Burton Federal Office Building's energy use by 25 percent, saving $450,000 per year.

The 1.4 million square foot structure is the largest federal building west of the Mississippi River. Energy-saving technologies being demonstrated at the building could save up to one-third of the federal government's annual energy bill of $4 billion if implemented in all federal buildings.

Figure 2: A contractor installs a dimming electronic ballast in a three-lamp lighting fixture at the Federal Building.

The team retrofitting the building consists of personnel from the Center for Building Science, the General Services Administration, Pacific Gas & Electric Company, the National Institute of Standards and Technology, and Energy Simulation Specialists. Members of the Center's Lighting Research Group and the Applications Team, which focuses on designing and implementing advanced energy-efficient demonstration projects, provided engineering expertise.

An advanced lighting controls testbed designed by Francis Rubinstein of the Lighting Research Group includes energy-efficient lighting for three floors of the building and a new automated control system. "Previous research that we've done at a demonstration site in Emeryville, California, has shown that by using integrated automated lighting controls, it's possible to reduce lighting energy use by up to 35 percent compared to a system without controls," says

Rubinstein. "These controls include, among others, automatically dimming the lights when daylight is available, dimming or turning lights off automatically when a space is unoccupied, and compensating for lumen loss as lights age. However, these 'first-generation' controls didn't have the intelligent features of current systems, and they were difficult to calibrate and maintain."

New lighting installed in the building includes more than 1,200 dimmable electronic ballasts, 3,600 efficient lamps, dozens of light and occupant sensors, manual and remote-control dimmers, and smart control panels that respond to changes in a space's occupancy and available daylight. Nearly 200 meters are monitoring the energy use of the testbed down to the level of individual rooms to determine how much energy and money the new systems are actually saving. The testbed is intended to prove that the more advanced second-generation lighting controls are cost-effective and energy-saving. It will also provide a basis for designing and specifying advanced lighting control systems in federal buildings throughout the country.

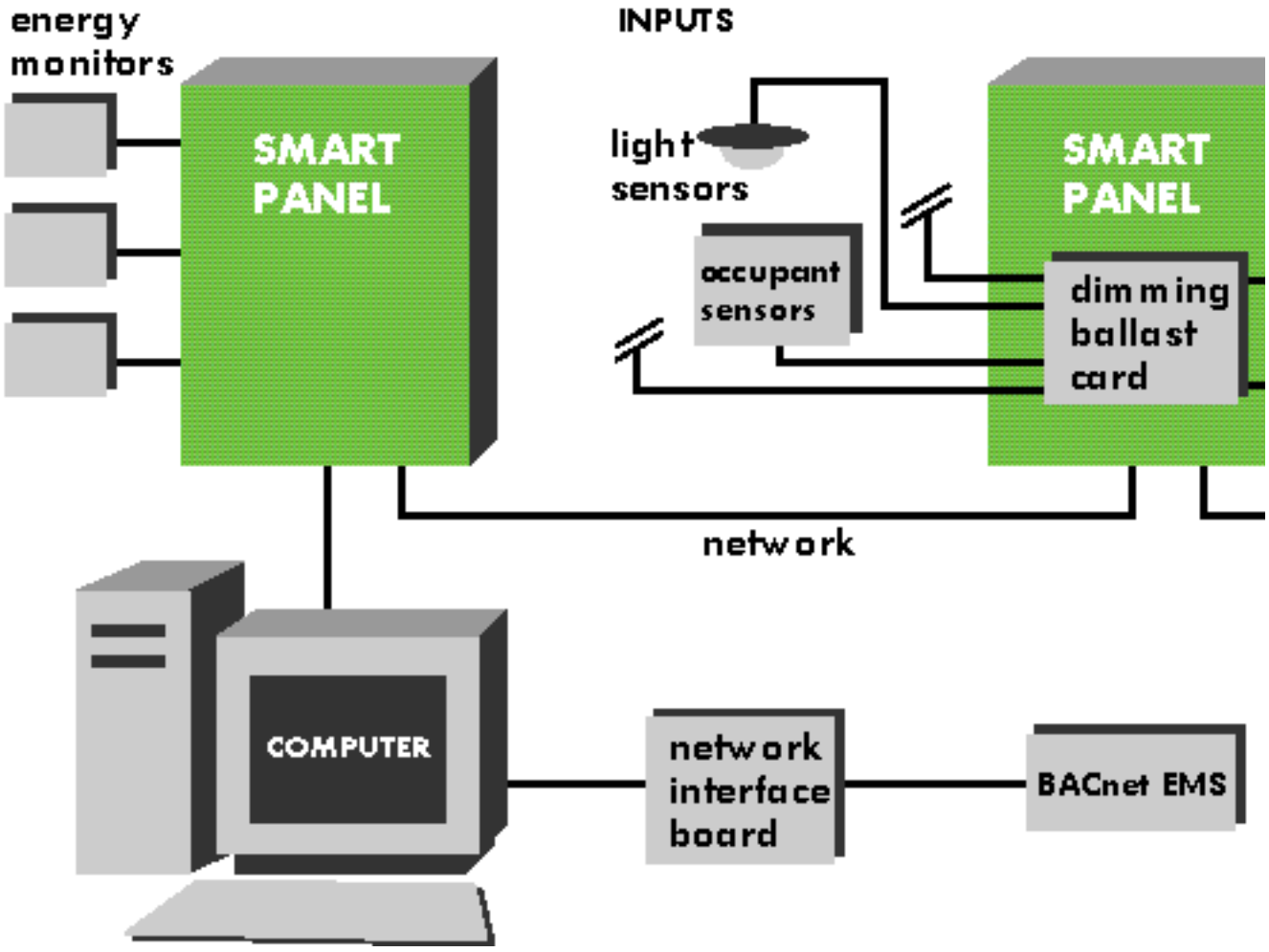

Figure 3: Occupant sensors, photocells, manual switches, and energy monitors are all connected to 40 "smart panels" distributed stragetically throughout the three-floor testbed. All the smart panels are interconnected and communicate over a simple twisted pair of wires.

The automated control system that regulates lighting will be coupled to other energy management systems, which regulate the building's heating, ventilation, and air-conditioning systems using a nonproprietary communications protocol standard called BACnet (building automation control network). The BACnet-based energy management and control system will let building managers monitor and control the lighting, HVAC, and metering systems, even if they are from different manufacturers.

Interconnecting all the meters in the Federal Building will help its operators provide the optimum level of lighting, heating, air conditioning, and other energy-consuming services using the lowest-cost energy. The GSA plans to interconnect other federal facilities in the San Francisco Bay Area using BACnet. Since the energy use of all these buildings will appear as a single account to the utility, GSA will get lower electric rates as a higher-volume user.

Center staff participating in the project include Rubinstein, Judy Jennings, Doug Avery, Dale Sartor, Steve Kromer, Kris Kinney, Joe Huang and Rick Diamond.

—Allan Chen

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CBS Newsletter
Winter 1997
pg. 5

Residential Ventilation & Energy

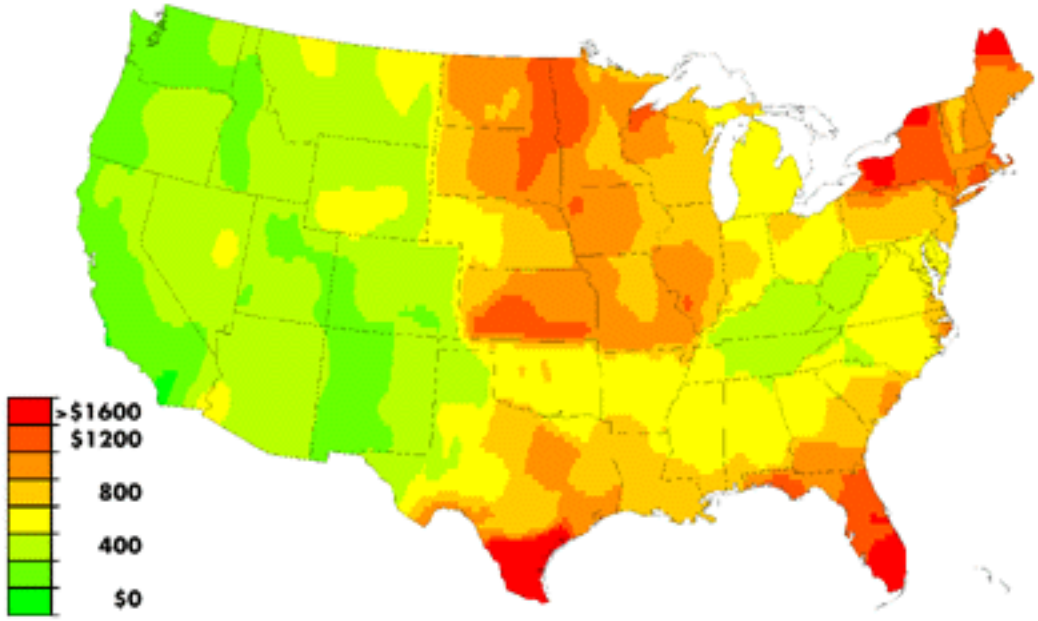

Figure 1: Annual Average Ventilation Costs of the Current U.S. Single-Family Housing Stock ($/year/house).

Infiltration and ventilation in dwellings is conventionally believed to account for one-third to one-half of space conditioning energy. Unfortunately, there is not a great deal of measurement data or analysis to substantiate this assumption. As energy conservation improvements to the thermal envelope continue, the fraction of energy consumed by the conditioning of air may increase. Air-tightening programs, while decreasing energy requirements, have the tendency to decrease ventilation and its associated energy penalty at the possible expense of adequate indoor air quality. Therefore, more energy may be spent on conditioning air.

In a recent report*, we used existing databases to estimate the energy and indoor air quality liabilities associated with residential ventilation in the U.S. housing stock, and how scenarios of energy conservation and ventilation strategies changed those liabilities. ASHRAE standards 62, 119, and 136 guided us in determining acceptable ventilation levels and energy requirements.

A straightforward modeling procedure, described in the report's appendix, can be used to estimate a house's heating and cooling demand, as well as its air-change rate. Rather than applying this to each of the 75 million single-family households in the U.S., we have combined data from a variety of sources using database management tools to develop average and aggregate estimates from each data source. The 1990 U.S. Census provided the number of houses for each county; the type and size of the houses were derived from DOE's Residential Energy Consumption Survey; their leakage properties were from the LBNL Leakage Database; and weather data came from standard databases of 240 sites and representative years for each site.

Characteristics of Current Stock

The ventilation rate of the stock is dominated by infiltration due to envelope leakage and is calculated from leakage distribution and weather data. These rates were calculated only to determine acceptable indoor air quality, not for energy calculations. We estimate that the average effective air-change rate is 1.1 air changes per hour (ACH) for the U.S., and that about 95 percent of current stock meets the intent of ASHRAE standard 62. The standard requires a minimum ventilation rate of 0.35 ACH.

Energy impacts associated with the high infiltration rates are large. The heating load attributable to infiltration and ventilation in the current stock is 3.4 EJ (exajoules), and the cooling load is 0.8 EJ. Using our air leakage and other databases, the estimated national annual cost to provide this much ventilation is $6 billion per year. The average annual cost per house would thus be $820/year, with costs ranging from $170 to $2,100 per house. The national cost distribution is shown in Figure 1.

Alternative Scenarios

The high cost associated with residential ventilation suggested that there may be cost-effective ways to reduce the infiltration rate. We developed a base case that was similar to the U.S. existing stock described above, and two alternative scenarios to test this hypothesis. In the ASHRAE scenario, the goal is to meet ASHRAE air tightness standard 119. The envelope is tightened as needed, and mechanical ventilation is supplied if necessary. The Scandinavian scenario is similar, except the tightness level is increased by a factor of two, based on Northern European trends.

In the ASHRAE scenario, the effective air-change rates range from 0.48 ACH to 1.18 ACH, with a national average of 0.52 ACH. The total energy load for the U.S. is about 1.8 EJ. The national annual cost is $3.6 billion, a reduction of $2.4 billion over the base case. The annualized cost of ventilation is $490/year for the average house, with a range from $130/yr to $1,000/yr. The annualized cost reduction is not as large as energy reduction due to purchase and operating cost of a mechanical ventilation system.

The Scandinavian scenario is modeled after the northern European shift toward tighter building envelopes and a small number of operable inlets. The optimal system configuration uses 1.6 EJ and has a national annual operating cost of $4 billion, a reduction of $2 billion over the base case. The annualized cost is about $550/yr for the average house, ranging from $210 to $860/yr per house.

For the country as a whole, the average cost saving is $330/house for the ASHRAE case and $270/house for the Scandinavian case. Assuming that, on average, house air-tightening costs $1,000/house and that the ventilation system operating cost savings are applied to this effort, a homeowner could expect a payback of under five years for air-tightening in either scenario.

—Max Sherman and Nance Matson

* "Residential Ventilation and Energy Characteristics," LBNL-39036, available from the authors; to be published in *ASHRAE Transactions*.

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Residential Ventilation Home Page

CBS Newsletter
Winter 1997
pg. 6

Residential Building Code Compliance: Recent Findings and Implications

Energy use in residential buildings in the U.S. is significant-about 20% of primary energy use. While several approaches reduce energy use such as appliance standards and utility programs, enforcing state building energy codes is one of the most promising. However, one of the challenges is to understand the rate of compliance within the building community. Utility companies typically use these codes as the baseline for providing incentives to builders participating in utility-sponsored residential new construction (RNC) programs. However, because builders may construct homes that fail to meet energy codes, energy use in the actual baseline is higher than would be expected if all buildings complied with the code. Also, builders participating in utility-sponsored RNC programs may have a higher frequency and level of building compliance than nonparticipating builders, resulting in additional resource savings. As a result, the measured savings from RNC programs may underestimate actual savings unless program participants' compliance with energy codes is taken into account.

In our analysis of six studies of building compliance in two regions of the U.S., the Pacific Northwest and California, we found a high number of violations in plans, in the field, and in energy impacts. However, where total energy consumption was calculated, on average the houses complied with the codes because the energy savings from the houses that saved more energy than called for by the code compensated for the excessive energy use of those that did not.

In three studies, compliance with state building codes was shown to be higher for participants in utility RNC programs than for nonparticipants. For example, in the evaluation of Pacific Gas & Electric's 1992 RNC program, nonparticipating homes in PG&E's service territory were, on average, built 6% below (i.e., did not meet) California's building energy codes based on calculated energy usage across all measures and equipment. In contrast, builders/contractors who agreed to participate in the PG&E program achieved 100% compliance. In a follow-up study, PG&E's program was found to have increased both the frequency and level of compliance with codes in the utility's service territory. Although both participating homes and non-participants were found, on average, to comply with California's code, the compliance margin of participating homes was nearly twice as great as that for nonparticipants. Furthermore, nonparticipant homes were more than ten times as likely to fail to comply than participant homes.

California, Oregon, and Washington have spent considerable resources on improving the expertise of builders and building code officials through training and educational programs. In addition, many jurisdictions in these states have had more than 15 years of experience with energy-efficiency codes, code support (by utilities, local government, and code officials), and code enforcement. In contrast, areas in the country with less experience and expertise will undoubtedly experience higher rates of noncompliance with state building codes. Accordingly, we believe utility RNC programs in other states could be more cost-effective if utility regulators recognized the role of RNC programs in increasing compliance with existing state building codes, or, conversely, if they recognize the general degree of noncompliance among nonparticipating builders. Finally, we expect the issue of building code compliance to continue to be an important research topic as utilities and governmental agencies promote energy efficiency through market transformation efforts. Market baselines (such as code compliance) are critical to evaluating the effectiveness of these efforts.

—Ed Vine

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For more information, request Ed Vine's paper presented at the 1996 ACEEE Summer Study: "Residential Building Code Compliance: Implications for Evaluating the Performance of Utility Residential New Construction Programs," LBL-38382.

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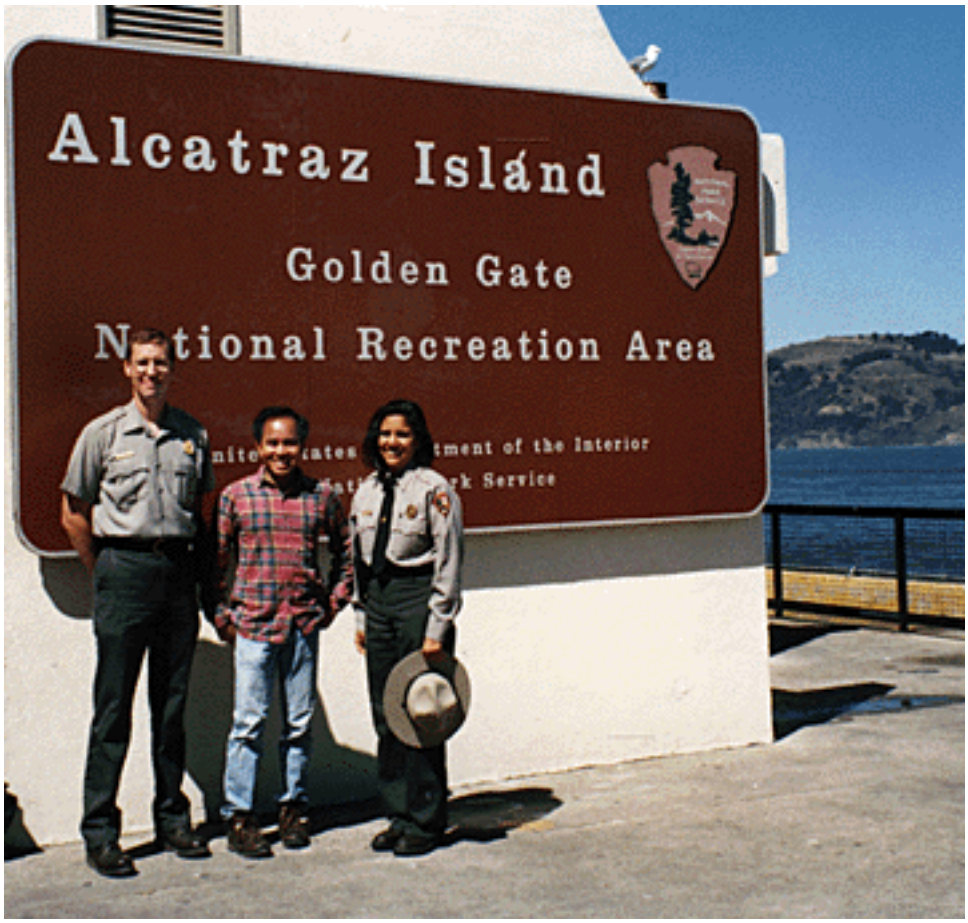
CBS Newsletter
Winter 1997
pg. 8

A-Team Report

The A-Team Does "The Rock"



Jim Christensen, Tai Voong, Naomi Torres

Not even Al "Scarface" Capone or Robert Stroud, the "Birdman of Alcatraz,"-two of the most infamous prisoners of Alcatraz-would notice a difference in the lighting. Yet a significant change has occurred in the amount of power used to light interior offices and exterior corridors on the island of Alcatraz. Incandescent lamps have slowly been replaced by compact fluorescents using about one-quarter of the power.

Since it is a historic landmark, Alcatraz is protected by the National Historical Society. Keeping the "look" of Alcatraz intact has made energy-efficient lighting retrofits challenging. Compact fluorescent lamps typically look dissimilar to incandescents in size, shape, and color. Finding lamps that would blend in took some research. Tai Voong, of Berkeley Lab's In-House Energy Management project, drew on his experience in lighting retrofit projects to put together specifications covering a selection of compact fluorescents he thought might work. These specifications were reviewed by Naomi Torres, the National Park Service's Interpretive Supervisor at Alcatraz Island. Jim Christensen, Energy Coordinator for the Golden Gate National Recreation Area, assisted with selecting compact fluorescents for testing.

As incandescent lamps have burned out, the National Park Service has replaced them with the more energy-efficient compact fluorescents. Torres has been alert to any feedback from the thousands of tourists that come daily to Alcatraz, but so far, she says, "no one has noticed the change." The only area in which fluorescent lighting will probably not be used is on the first floor of the cellhouse, where tourists peer into cells lit by a single bare incandescent.

Voong's work at Alcatraz is a project of the Center's Applications Team. To evaluate the cost effectiveness of various energy-efficient retrofits on the island, he has been using data loggers to monitor all of the electrical consumption for more than a year.

Another area of concern is the two diesel-fueled generators that provide the power for lights, motors, pumps, and miscellaneous plug loads. Because of the pollution and noise generated along with power, representatives from the A-Team, the National Park Service, Sandia Laboratory, and the National Renewable Energy Laboratory have been studying cleaner systems for power generation at Alcatraz. One conclusion is that even though Alcatraz has more than enough wind to capture its energy in a power generation system, wind turbines in all potential locations are visible to tour boats. However, the researchers have found a possible location for a photovoltaic power system that would keep it hidden from view. In the meantime, the National Park Service is doing what it can to reduce consumption of the costly diesel fuel.

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This work is sponsored by the Federal Energy Management Program.