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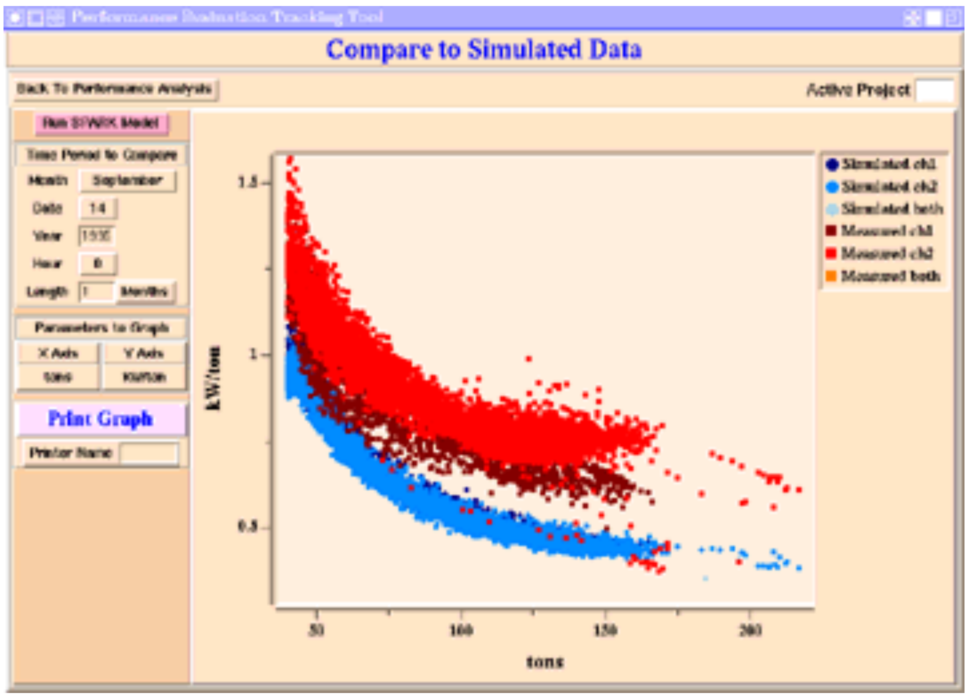
Green Cooling: Improving Chiller Efficiency



This new chiller simulation module being developed by Building Performance Assurance Project members will help building managers compare optimal and actual chiller efficiency.

Chillers are the single largest energy consumers in commercial buildings. These machines create peaks in electric power consumption, typically during summer afternoons. In fact, 23% of electricity generation is associated with powering chillers that use CFCs and HCFCs, ozone-depleting refrigerants. Satisfying the peak demand caused by chillers forces utilities to build new power plants. However, because chiller plants run the most when the weather is hot and very little at other times, their load factors - and hence the utilities' load factors (the percentage of time the power plant is generating electricity) - are low. Thus, to utilities, chillers are more costly to serve than other loads.

The phase-out of CFC refrigerants, intended to protect the ozone layer under an international agreement, has triggered an unprecedented wave of chiller replacements that will accelerate during the next 10 years. Energy-efficiency measures implemented in conjunction with chiller retrofits can reduce the load and therefore the required chiller size, making the change more economical overall. But once the chiller is replaced, the opportunity for an integrated approach is lost. Most chiller plants are oversized, and even those that are correctly sized operate most of the time at low part-load efficiencies. New technologies such as direct digital controls and variable frequency drives, combined with improved design, commissioning, and operation, can decrease chiller plant energy consumption by more than 50% while improving their reliability and helping the environment.

Chiller projects in which the Center participates include:

DOE's In-House Energy Management Integrated Chiller Retrofit Program.

The Department of Energy anticipates a need for more than $200 million in chiller upgrades in response to aging cooling plants and the phase-out of CFCs. Direct line-item Congressional funding for these projects is unlikely. Integrating energy-efficiency measures (load reduction) with chiller upgrades and correctly sizing the chillers can increase a project's cost-effectiveness and may allow DOE facilities to fund their own retrofits through innovative energy savings performance contracts. The LBNL Applications Team (CBS News, Fall 1994, p.1) is developing an implementation guide and sample documents to facilitate such contracts. We will also specify a chiller plant monitoring tool kit to help facility managers determine the load for optimum sizing and system configuring and to establish the baseline under an energy savings performance contract.

The Building Performance Assurance Project.

The goal of this effort is to improve building performance by creating building life-cycle information systems (CBS News, Summer 1995, p.1). Much of the first year's work focused on developing computerized commissioning tools and performance tracking of chiller plants. The Center's three programs (Building Technologies, Energy Analysis, and Indoor Environment) and LBNL's Computing Division are involved in this effort. Project participants are now integrating chiller plant design, commissioning, performance tracking, and operations and maintenance tools into a single computing environment. Laboratory Directed Research and Development support funds this project.

The Remote Building Monitoring Project.

Now in its first year, this project is focused on monitoring and tracking chiller performance over the Internet. The second-year goal is to include control for optimization under real-time pricing. In subsequent years, the project will expand control and diagnostic capability and integrate other building systems.

Energy audit of the U.S. Embassy in India.

This project began when Secretary of Energy Hazel O'Leary and the Ambassador to India signed an agreement to upgrade the energy efficiency of American embassy facilities in New Delhi and to make the embassy a showcase of American technology. Applications Team member Brad Gustafson, who is based in Washington, D.C., at the Federal Energy Management Program, joined representatives of the State Department and a private company in auditing about 37,000m2 (400,000 ft^2) of embassy facilities, including the ambassador's residence, office space and support areas, and a U.S. Information Services building separate from the embassy grounds. The team recommended short-term improvements and long-term chiller upgrades, and provided information to help embassy staff evaluate requests for proposals for an energy savings performance contract.

The CIEE Building Diagnostics Program.

With funding from the California Institute for Energy Efficiency, a multi-institution team is examining chiller plant failure mode analysis and evaluating techniques for detecting and diagnosing the failure modes. One objective of this work is to develop a knowledge-based system to help diagnose chiller failures and devise strategies to correct the problems. Advanced data visualization will play a major role in the diagnostics project.

The Center's researchers and Applications Team members are working on other projects involving chiller efficiency upgrades, monitoring, and verification and developing innovative ways to determine and optimize chiller plant performance. The projects in which the A-Team is participating are here. Thanks to these many efforts, LBNL's "center of exellence" in chiller plant efficiency will help ease the phase-out of CFC refrigerants and the transition to better chillers. Not only have chiller manufacturers introduced more efficient products than the machines they will replace, there are considerable opportunities to improve chiller plant design, system integration, and operations as well. LBNL's work in developing advanced tools for design, performance monitoring, commissioning, diagnostics, and control and innovative financing of energy-efficient chiller projects will help capture some of the savings through new technology.

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News From the D.C. Office

Federal Procurement of Efficient Chillers

The replacement of large electric chillers in government facilities, driven by the phase-out of ozone-depleting chlorofluorocarbon refrigerants, presents a major opportunity to improve energy efficiency. LBNL's work for the Department of Energy's Federal Energy Management Program (DOE/FEMP) is aimed at using Federal purchasing power as a source of market pull for energy-efficient equipment, including chillers. While this effort focuses on the efficiency of the chiller itself, other LBNL activities address system interactions.(See the accompanying cover article by Dale Sartor and Allan Chen.)

Chillers are typically long-lived (25 years or more) and represent a significant capital investment. Thus, CFC replacement programs create an opportunity for all building owners, including the Federal government, to achieve substantial energy savings that will continue for many years. Also, at a time of declining funds for energy-efficiency investments, Federal chiller replacements represent a major new source of capital investment in energy savings as well as removal of CFC refrigerants. For example, Federal agencies are planning to spend $500 million during the next several years to replace or upgrade the 4,000 chillers now using CFC refrigerants. This represents 40% of the total spending by

Federal agencies in the past 10 years on all other energy efficiency projects combined ($1.3 billion from 1985 to 1994).

The $4 billion spent each year on energy in Federal facilities includes the cost of operating these older chillers-nearly half of which have efficiencies between 0.8 and 1.1 kW/ton, according to a 1994 DOE survey. Today's best available commercial chillers offer efficiencies in the 0.5 to 0.6 kW/ton range. According to DOE, the energy savings from replacing just the largest (more than 100 tons) water-cooled chillers in Federal facilities is estimated at $75 million annually, or $1.4 billion (present value) over their 25-year life. Projected total savings in Federal facilities from the purchase of more efficient chillers, including lower electricity bills and avoided pollution costs, are estimated at more than $2 billion.

To streamline the procurement process and reduce the cost of replacement chillers, DOE Defense Programs is working with manufacturers to develop a Basic Ordering Agreement through the General Services Administration. This will allow purchasers in all Federal agencies to take advantage of quantity pricing and a simpler, speedier procurement process. The GSA approach gives all Federal buyers product selection while addressing energy efficiency, safety, reliability, and other performance issues through a new standard specification. Administrative costs savings are projected at $38 million.

As part of a project for DOE/FEMP led by the LBNL Washington Office, we are coordinating with DOE Defense Programs and GSA to assure that chillers purchased through the Basic Ordering Agreement meet the intent of Executive Order 12902 and the 1992 Energy Policy Act. The Executive Order directs Federal agencies to purchase best-practice energy-efficient products that are in the upper 25% of the market in terms of efficiency.

In cooperation with the DOE In-House Energy Management Program, the New York State Energy R&D Authority, and the State Procurement Collaborative, LBNL has helped develop energy efficiency specifications for water-cooled centrifugal and screw compressors. These criteria are based on manufacturer-reported data using established Air Conditioning and Refrigeration Institute test methods and set minimum levels for either full-load or part-load performance (depending on the intended use of the chiller). The criteria start with the 25% most efficient chiller models on the market, with adjustments made to assure multiple sources of supply to maintain a competitive procurement process.

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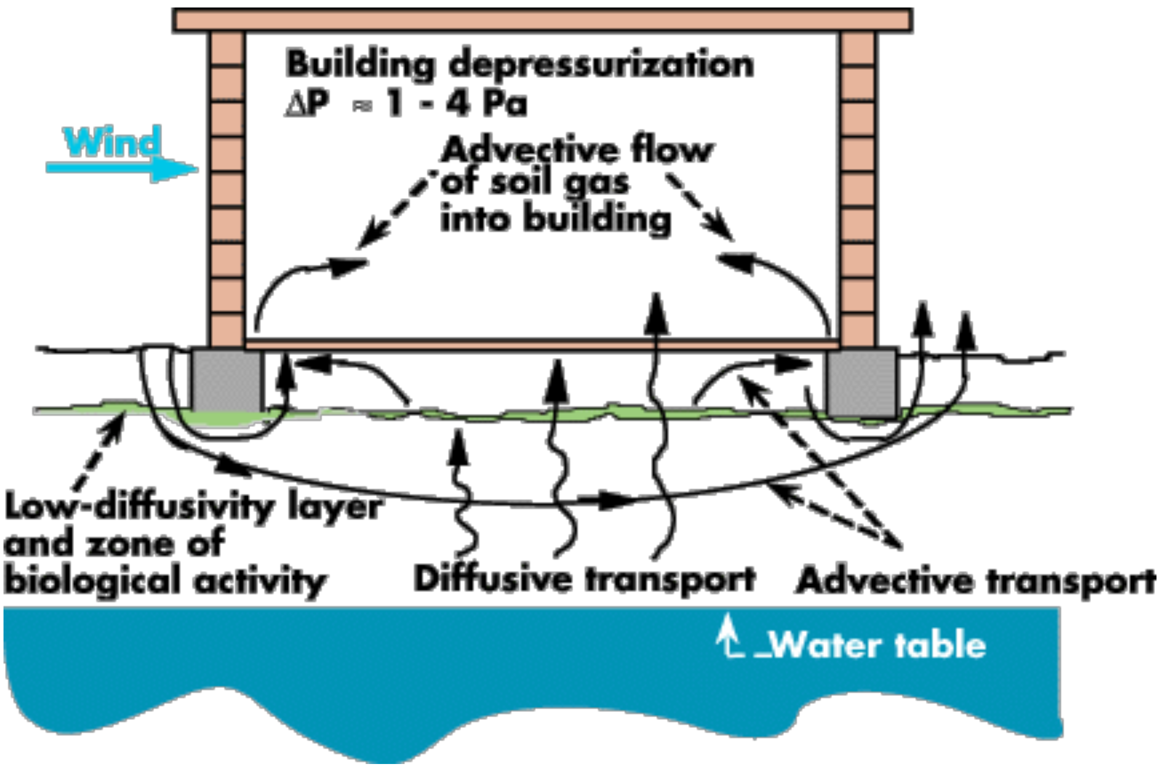
Subsurface Gasoline Contamination: An Indoor Air Quality Field Study



Schematic of soil-gas and contaminant transport into a slab-on-grade building at a former service station site. Three effects are illustrated that can contribute to reducing the amount of contaminant available for entry into the building: biodegradation by soil microorganisms; a layer of soil that limits diffusive movement of the contaminant; and wind-driven ventilation of the soil below the building. Not illustrated are the effects of ventilation on contaminant concentrations inside the building.

The transport of soil-gas-borne contaminants into buildings has been documented as a significant source of human exposure to some pollutants indoors; one example is radon, which has received widespread public attention. Other gas-phase chemicals, such as volatile organic compounds, may show similar behavior, although these have received less scientific and public attention. Leaky underground storage tanks for gasoline and other petroleum hydrocarbons are a cause of concern for several reasons. Exposure to some of the compounds in these mixtures has known human health implications, and studies have reported indoor air contamination by some of these species. Also, a large number of storage tanks-some in urban areas-are leaking. Estimating indoor air VOC concentrations caused by subsurface sources is an important input to assessments of health effects and assignments of priorities for remediation activities. However, because such estimates of exposure usually depend on the sophistication of the models and their assumptions, the results often vary by orders of magnitude.

In an effort to understand the factors that affect soil gas contaminant transport into buildings, we conducted a field study at a former gasoline service station building at the Alameda Naval Air Station (ANAS), in California. This station was closed in the late 1980s following gasoline leaks from a damaged underground storage tank and from feed lines to the dispensing pumps. We began by measuring the VOC concentrations in the outdoor and indoor air, soil gas, and groundwater. Although high concentrations (~30 g m^[-3]) of several compounds found in gasoline were measured in the soil gas 0.7 m (2.3 ft) below the building, the measured indoor air concentrations in the building were approximately six orders of magnitude lower, a much larger difference than the three orders of magnitude more typically observed. Our study then focused on factors that might limit or influence transport, and on the potential for biological degradation of the VOCs. Measurements included depth profiles of selected VOCs, CH_4, O_2, and CO_2; the chemical and physical properties of the soil; tracer-gas tests of diffusive and advective transport in the soil and of the buildings ventilation characteristics; and a controlled test of the rate of biodegradation of selected VOCs in the soil.

The soil-gas concentration profile of several chemical species in the soil below the building showed a sharp increase in the isopentane (a volatile constituent of gasoline) and methane concentrations between depths of 0.4 and 0.65 m (1.3 and 2.1 ft) compared with concentrations at shallower depths. At the same time, the concentration of CO_2 also increased somewhat while that of O_2 decreased, again with the largest changes observed at depths between 0.45 and 0.6 m. Because these concentration profiles are suggestive of aerobic consumption of the hydrocarbons by soil microorganisms, we performed laboratory incubation experiments using soils collected from the site at various depth intervals. The biodegradation rates observed in the laboratory experiments were somewhat greater than those observed in the field but appear to be consistent when accounting for the differences between the conditions of the lab and field experiments are taken into account.

We combined these results in the context of a simplified schematic model, illustrated in the figure, to estimate the effects of building ventilation, physical limitations to soil-gas transport, and biodegradation on indoor contaminant concentrations. As the figure suggests, the combination of biodegradation and restricted transport in the low-diffusivity layer below the building alters the amount of contaminant in the soil gas available to be transported into the building. We estimate that dilution of soil gas entering the building via ambient ventilation reduces the VOC concentration by a factor of ~1,000, that the physical limitations to transport reduce the soil-gas concentrations of all gas species by a factor of ~10, and that biodegradation reduces the concentration of these VOCs by another factor of ~100.

These physical and biological processes are likely to affect indoor air concentrations of contaminants to varying degrees at other sites. Although aliphatic petroleum hydrocarbons may undergo near-surface aerobic biodegradation faster than other compounds in less aerobic environments (particularly halogenated hydrocarbons in the deep subsurface), these and other types of biodegradation may have a substantial effect on the indoor air concentrations observed at a site. Our results-the unanticipated low levels of VOCs in the ANAS facility-suggest that estimating VOC transport into buildings in a site or risk assessment requires careful attention to identifying and separating physical and biotic effects.

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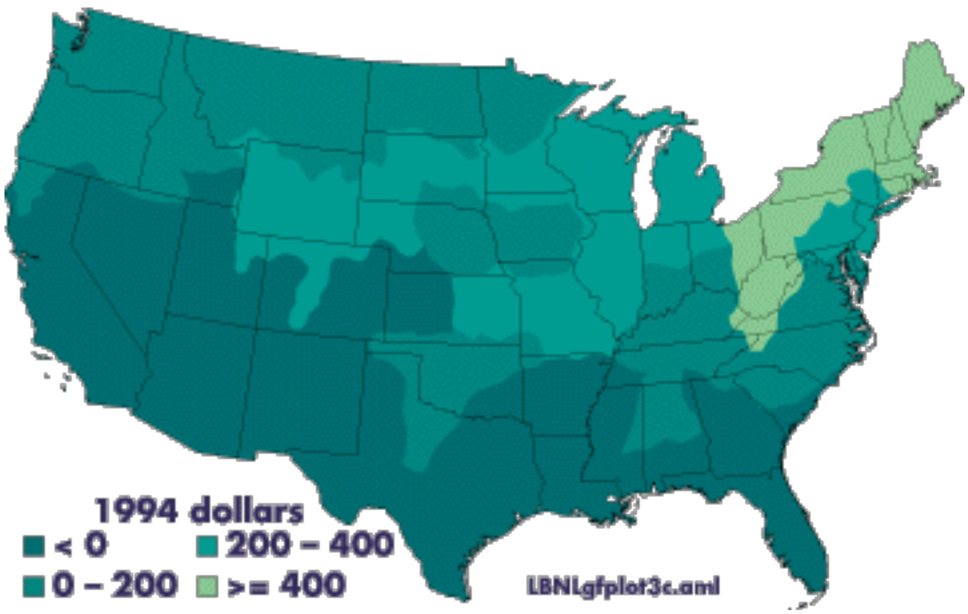
Residential Assessment of Market Potential (RAMP)



Life-cycle cost savings per household for a condensing gas furnace compared to a standard gas furnace. Assumes 18-year lifetime, 7% discount rate, and $800 incremental purchase price.

Energy-efficient products can provide environmental benefits, but their true potential can only be realized when these products have achieved widespread market acceptance. The Residential Assessment of Market Potential (RAMP) project's purpose is to help the Environmental Protection Agency (EPA) design programs that meet the residential-sector greenhouse-gas stabilization goals of the Climate Change Action Plan. The results of RAMP research facilitate the design of voluntary, "market-pull" programs that reduce pollution by accelerating the penetration of new or under used, energy-efficient technologies for most residential end-uses.

The RAMP team is assessing the market potential of many energy-efficient products such as ground-source heat pumps, condensing gas furnaces, and a variety of home appliances. The policy makers who implement energy efficiency use this information to design programs that target the most attractive market segments. The EPA can use RAMP research to promote efficiency through program mechanisms such as product labeling, home builder initiatives, Home Energy Rating Systems and Energy-Efficient Mortgages, partnerships with realtors and financiers, and utility-sponsored incentive programs.

To assess the market for energy-efficient products, we first focus on how residential products are purchased and used, the existing market infrastructure for efficient products, and the barriers to increased market penetration of these products. We use existing survey data or conduct informal interviews to gather data pertaining to the functioning of markets. We then apply a detailed model, based on geographic information system (GIS) analysis, to identify market segments in which efficient technologies are technically feasible, cost-effective, and acceptable to consumers. The advantage of the GIS is that it can incorporate data (such as climate data, utility rates, building thermal characteristics, and equipment saturations) at several levels of regional detail and produce results in map format that are easy to understand and act upon. Our market assessment model uses individual household data from the Residential Energy Consumption Survey and the American Housing Survey as well as summary data from the 1990 census.

The key feature of RAMP analysis is that research results are disaggregated as much as possible to distinguish the market potential among regions, house types, demographic groups, and other market segments. Within each market segment, we estimate the potential for efficient technologies to save energy and prevent pollution assuming either a business-as-usual scenario or the implementation of various programs to promote energy-efficient products.

This type of analysis helps answer such important questions as:

- Which households are better off as a result of energy-efficiency performance standards?
- Where is a particular energy-efficient product most cost-effective from the perspectives of the consumer, utility, and society?
- Which customers should be targeted for a particular energy-efficient product? What is the best way to locate them?
- Where is the best place to locate a pilot energy-efficiency program?
- Based on regional cost-effectiveness, which appliance efficiency levels should be eligible for promotion or rebate?

- In a given area (such as a neighborhood), how many households own particular appliances, and how many are likely to buy replacements or new appliances in the next few years?
- Where is the housing construction market most active, and what are the associated opportunities for promoting energy-efficient technologies in new homes?

An example of how we have applied the market assessment model is our assistance to program managers designing a pilot program to promote the sale of efficient heating and cooling equipment. We used the GIS model to determine the most cost-effective regions for several energy-efficient heating and cooling products. The figure illustrates the national analysis results of the life-cycle cost savings for a condensing gas furnace compared to a standard gas furnace.

We further narrowed the potential areas for launching the program by identifying metropolitan areas with sufficient energy-efficiency market infrastructure and other favorable factors (such as utility program activity) and screening for neighborhoods with favorable demographic and housing characteristics. The results of this screening process were used to establish a direct mail campaign and to help local HVAC contractors target their marketing efforts.

—The RAMP Team

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Windows as Luminaires

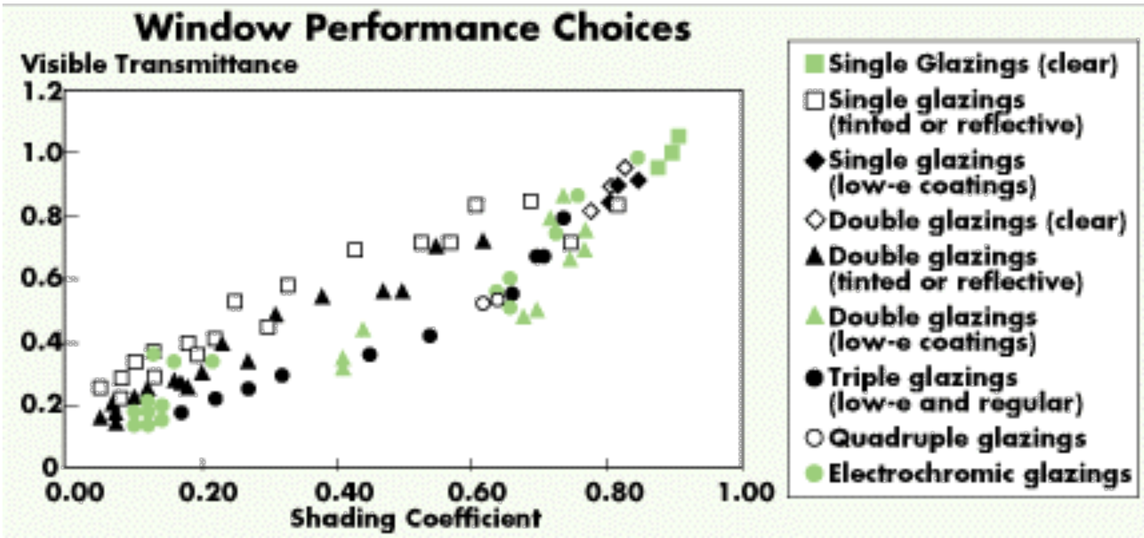


Figure 1. Variations in visible transmittance and shading coefficients for various glazing products. With the exception of electrochromics, the figure represents products available on the U.S. market in 1992. (From the Window Library in the DOE-2 building energy simulation program.) Note: The next revision to this database will report solar properties as Solar Heat Gain Coefficient, which is now gradually replacing Shading Coefficient in product literature as the key solar parameter.

Recent advances in technology have helped make the window an ally in efforts to save lighting energy. New window technologies can help minimize unwanted solar gains in summer as well as heat losses in winter, without squandering valuable daylight.

It is useful to think of a window as a luminaire. Windows are sources of light and have distinct optical characteristics and implications for visual comfort. Of course, they are also sources of heat gains and losses. Although the field of daylighting is as old as architecture itself, recent advances in window technology, aided by LBNL research, have opened up new opportunities for reducing electrical lighting requirements in buildings.

As is so often true, efforts to improve the energy efficiency of a technology-in this case windows-have led to a dramatic expansion of consumer choices. In addition to multiple glazings, efficient window options now include a host of shading systems, low-emissivity and selective coatings, gas fillings, and daylight integration (for example, via dimming ballasts). Smart, switchable glazings are just around the corner.

A host of non-energy-related benefits tend to accompany energy-efficient window systems. For instance, they generally have lower sound transmittance and reduce the amount of damaging ultraviolet rays entering a building. Efficient windows also offer better thermal comfort: their interior surfaces are cooler in summer and warmer in winter.

New Technologies

Windows are one of the most complex energy-using technologies in buildings. They play a role in lighting, heating, cooling, and ventilation. Aesthetics-appearance, view, and optical performance-are usually quite important to the occupant. Indeed, the serious lighting designer cannot ignore the energy implications of window choices.

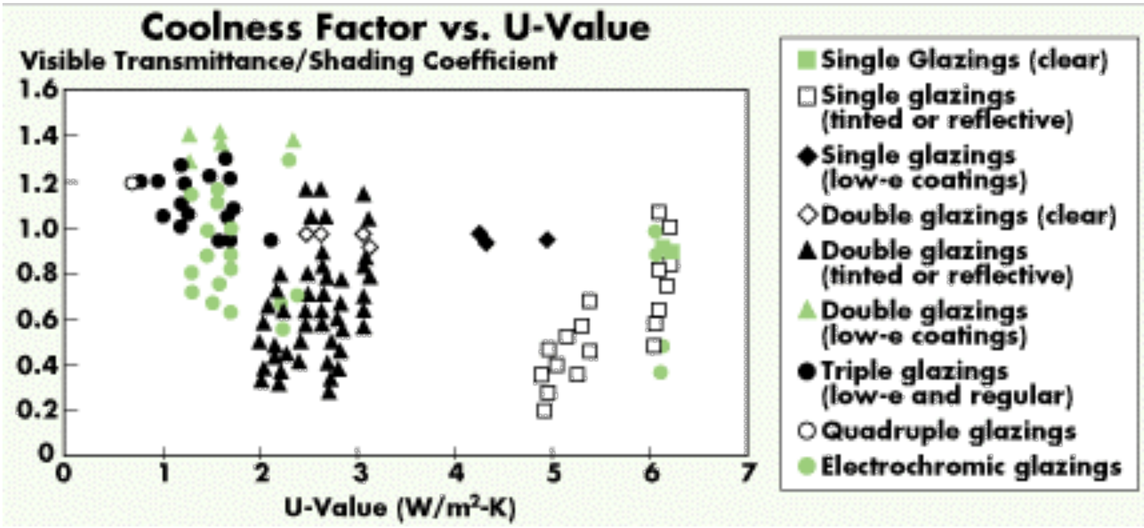
New technologies help to resolve the historic problem of the trade-off between windows that reflect unwanted solar gains in the summer and those that admit a maximum amount of useful light. Todays window technologies can replace more primitive strategies for shielding a room from unwanted sunlight, such as tinted windows and curtains. Tinted windows have the disadvantage of absorbing solar radiation and can become very warm (up to 50 degrees C). Some of this heat is then radiated to the interior space, causing discomfort to anyone nearby. Tinted windows also impede the building occupants' view of the outside environment and require higher artificial lighting energy use to compensate for daylight loss. Similarly, multiple-paned windows can effectively retain heat in the winter but filter out useful daylight.

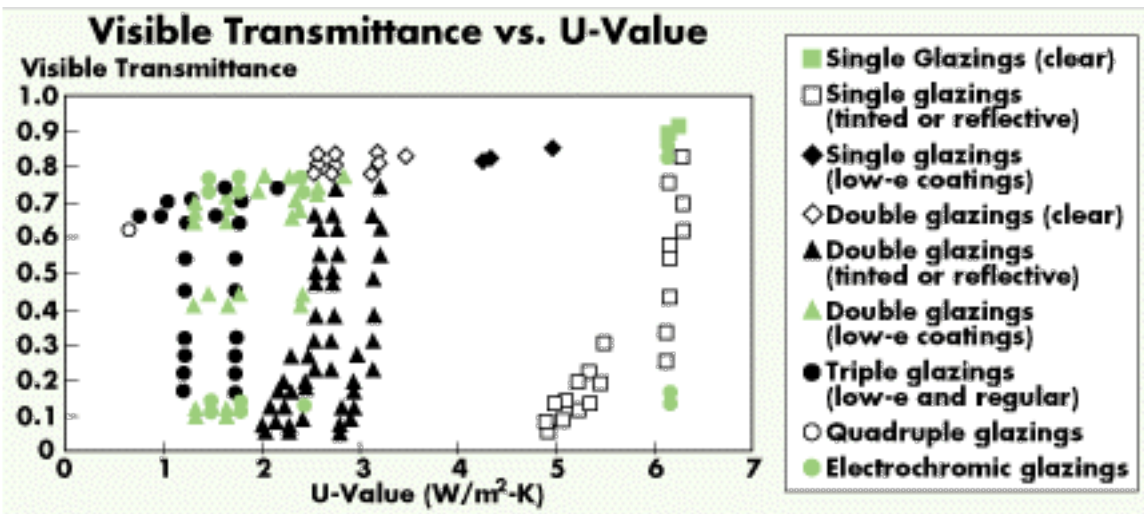
In hot climates, spectrally selective glazings admit visible light wavelengths while reflecting unwanted infrared wavelengths. The larger the ratio of a window's visible transmittance to its shading coefficient (a measure of solar transmission) the greater is its selectivity. This "coolness factor" ranges from a ratio of 0.25 to 1.6 for windows sold today.

In cold climates, low-e coatings are of interest. These nearly invisible, multilayer coatings are deposited on glass or plastic at the time of manufacture or as an off-line process. The coatings reduce radiative heat losses by reflecting heat back into the building. The bottom-line effect is an increase in the insulating value of the window. For even better performance, gaps between the layers of multiglazed windows can be filled with gases-such as argon, krypton, or xenon-that have better insulating properties than air. Windows with low-e coatings have already captured a 35% market share in the U.S, with sales of 25 million square meters (270 million square feet) per year.

Fig. 1 is based on a comparison of about 200 glazing products, including single-, double-, triple-, and quadruple-pane glazings with different tints, coatings, gas fills, glass thicknesses, and gap widths. Visible transmittance varies from 0.15 to 1.0. Shading coefficients vary from 0.05 to 0.9.

Fig. 2a plots the coolness factor as a function of the U-Value, showing that, for example, in the U-value range of 2 to 3, the coolness factor ranges from 0.2 (low visible transmittance in relation to solar gain) to 1.4 (very well-managed solar heat gain and good visible transmittance). Remarkably, visible transmittances vary from roughly 0.2 to 0.8 over the entire range of insulating values (Fig. 2b).





Figures 2a and 2b. Over a range of thermal efficiencies, (U-Value), windows vary considerably in their spectral selectivity (above) and visible transmittance (below).

"Smart" Windows

Since both thermal and luminous conditions are constantly changing, the ideal window should have properties that can be dynamically controlled.

Once a fantasy, such "switchable" windows are now becoming a reality in the Center's research laboratories and are moving toward the marketplace. With one of the most promising types of switchable glazings-electrochromics-the optical density can be controlled as a functional parameter, such as a function of direct or total solar radiation, outside temperature, the previous-hour space-conditioning load, or the indoor daylight level. Electrochromatic window properties are changed by applying a very small electrical voltage across the electrochromic coating (Fig. 3). If used in conjunction with electronic dimmable ballasts, electrochromic windows can help attain considerable lighting energy savings relative to static window shading systems.

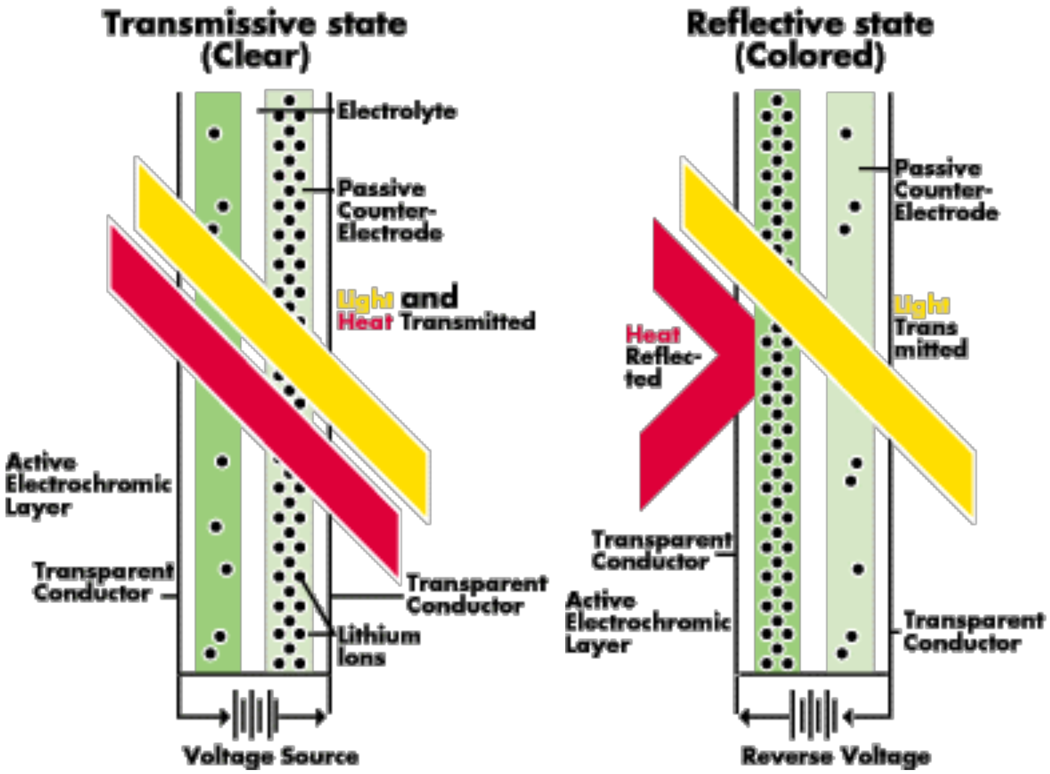


Figure 3. Cross section of prototype five-layer electrochromic coating in clear and colored states (layers not to scale).

Prototype electrochromics being developed by the Center's Building Technologies Program have shading coefficients that can be adjusted from 0.98 to 0.36 and visible transmittances from 0.85 to 0.13. Such windows will free designers from the historical rule-of-thumb that energy use eventually increases as a function of ratio of window-to-wall areas. Even in very hot climates, energy use can decline steadily with increasing window area if electrochromics are used with daylighting controls, whereas conventional windows inevitably increase energy use as their size increases.

Economics

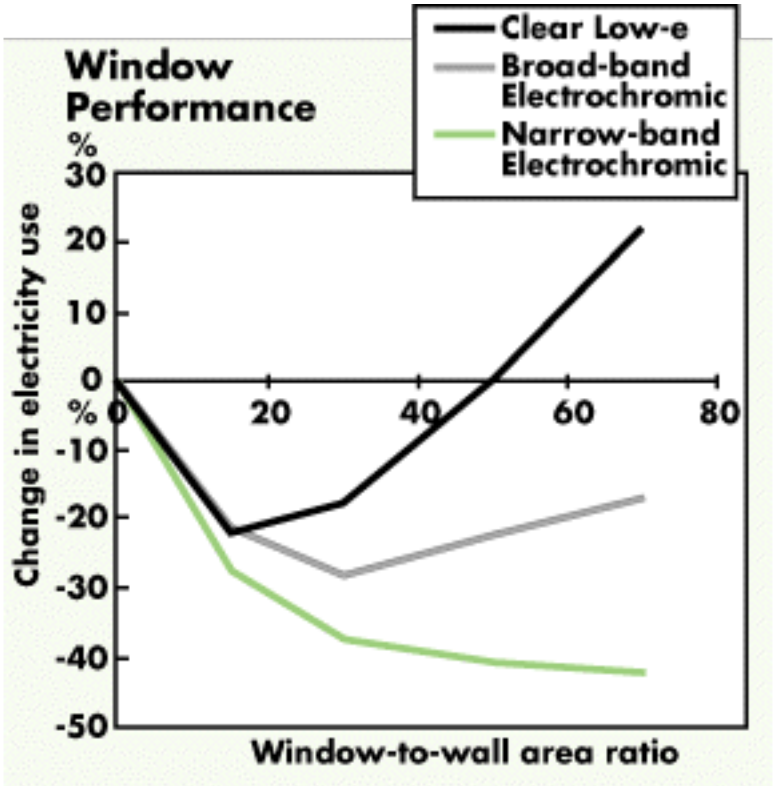


Figure 4: Change in total energy use for cooling, fans and lighting for a west-facing perimeter zone in a prototype commercial office building located in Blythe, California. Results are shown for idealized electrochromic windows and a static glazing for varying window-to-wall area ratios. The electrochromic windows are controlled to maintain an interior daylight illuminance level of 538 lux. All systems use electronic ballasts with continuous dimming daylight controls and a lighting power density of 16.1 W/m2. (Calculations made with DOE-2 by E. Lee, Lawrence Berkeley National Laboratory.)

The market price of advanced window technologies vary widely. In markets where the technologies aren't well-known, prices can be extremely high (if the product is available at all). By contrast, in markets with considerable production and demand or where utility rebates or building codes call for such windows, prices can be quite reasonable.

System cost-effectiveness is determined by a combination of many factors. For new construction, the higher costs can often be partially-or even completely-offset by cost savings made possible by HVAC downsizing. In this case, the payback time is instantaneous, and any extra savings are pure profit.

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A-Team Report

The Applications Team is a joint venture of the Energy & Environment Division and the Lab's Facilities/In-House Energy Management Section. Its goals are to speed the transfer of new and underused energy-efficient technology for buildings, to support demonstrations of these technologies in a variety of facilities showing how they can be adopted widely, and to improve communication between the Lab and the users of efficient building technologies, from engineering construction firms to building managers. The A-Team is involved in a growing number of chiller plant efficiency projects aimed at demonstrating how cooling systems in many settings can be made more efficient.

In addition to the projects described in the cover story, A-Team efforts in chiller retrofit include:

- The Advanced Data Visualization project, which focused on several chiller plants to develop and demonstrate new tools for performance analysis.
- Providing input to DOE and GSA on their standard chiller procurement initiatives.
- Support on chiller plant design and retrofit in numerous Federal Energy Management Program design assistance projects. For example, the Presidio of San Francisco is considering a retrofit and right-sizing of a 500-ton chiller in an oversized chiller plant.
- Metering and monitoring of numerous chiller plants for tuning, retrofit assessment, thermal storage sizing, and baselining under energy savings performance contracts. For example, an LBNL building was the DOE pilot test for a comprehensive energy savings performance contract. Chiller plant savings are measured using a baseline regression model incorporating weather, process electrical use, and gas use. Another recent example was an instrumented study on numerous air conditioners at a U.S. embassy in India.
- Developing National Measurement and Verification protocols and FEMP M&V

- A CIEE project to improve the energy efficiency of laboratory and related facilities in California. The focus of this project is to produce a design guide that, among other benefits, reduces chiller oversizing and optimizes part-load chiller plant efficiencies.

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