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Energy Analysis Program

1991 Annual Report

Energy & Environment Division

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Energy Analysis Program 1991 Annual Report

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LBL-32108

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Introduction

For most of the 1980s in the United States, energy and environmental issues were considered less important than a wide range of other public policy issues. This perception has changed as the nation enters the 1990s. Energy and the environment are at the forefront of many agendas: at the national level, Congress and the Department of Energy have discussed comprehensive energy legislation for the first time in more than ten years; at the state level, state government programs actively encourage energy efficiency; many more active public utility regulatory commissions have emerged; utilities are promoting demand-side programs to increase profits in several key states on both the East and West Coasts; and other local agencies have also become involved. For the first time, energy issues are an important element of the international agenda as well: a framework convention on greenhouse gas emissions is currently under discussion as the major nations make preparations for the United Nations Conference on Environment and Development in Brazil.

The Energy Analysis Program has played an active role in the analysis and discussion of energy and environmental issues at several levels:

- at the international level, the Program has been serving as the key analytic team developing scenarios for long-term energy demand in developing countries (for the U.S. Environmental Protection Agency);
- the Program led an effort that produced a key report, "Electricity End-Use Efficiency: Experience with Technologies, Markets, and Policies Throughout the World," submitted by the U. S. Department of Energy to the Intergovernmental Panel on Climate Change;
- the Program organized and led an analytic effort, "Energy Efficiency, Developing Countries, and Eastern Europe," as a major contribution to an organized activity to increase support for energy efficiency programs worldwide;
- produced a major book on energy use in the OECD, to be published by Cambridge University Press and entitled *Energy Efficiency and Human Activity: Past Trends, Future Prospects;*
- at the national level, the Program has been responsible for assessing energy forecasts and policies affecting energy use (e.g., appliance standards, National Energy Strategy scenarios);
- at the state and utility levels, the Program has been a leader in promoting integrated resource utility planning; the collaborative process has led to agreement on a new generation of utility demand-side programs in California, providing an opportunity to use knowledge and analytic techniques of the Program's researchers.

The past year has seen a continuation of our research emphases as well as some important new initiatives. We continue to place highest emphasis on analyzing energy efficiency, with particular attention given to energy use in buildings. The Program continues its active analysis of international energy issues in Asia (including China), Eastern Europe and the former Soviet Union, South America, and Western Europe. Analyzing the costs and benefits of different levels of standards for residential appliances continues to be the largest single area of research within the Program, although increases in federal support for a wide range of energy issues relating to global climate change may shortly become our largest analytic activity.

An important new initiative has come to fruition during the past year: the development and application of techniques for forecasting energy demand (or constructing scenarios) for the United States. We have built a new model of industrial energy demand, are in the process of making major changes in our tools for forecasting residential energy demand, have built an extensive and documented energy conservation supply curve of residential energy use, and are beginning an analysis of energy-demand forecasting for commercial buildings. Two new initiatives are on the agenda for future years: providing energy assistance for—and collaborating with—developing countries and establishing a comprehensive research program on environmental aspects of energy development and use.

Overall, 1991 has been a year of increasing Program activity and expansion on several fronts. We anticipate continued expansion over the next several years.

BUILDING ENERGY ANALYSIS

Commercial Load Shapes and End-Use Intensities for Offices and Retail Stores in Northern and Central California

H. Akbari

This study, sponsored by the Pacific Gas & Electric Company (PG&E), focused on the application of a new end-use load shape estimation technique and the development of a database of commercial sector end-use load shapes and end-use intensities (EUIs). The database will be used by the California Energy Commission and PG&E in their commercial energy and peak load forecasting models. The technique relied on a unique reconciliation of whole-building hourly electricity load data to energy simulations, which were developed from detailed survey data. The outcome of the project is a set of reconciled load shapes for as many as ten end uses in two building types that are then indexed for three building vintage and technology combinations.

The building types studied are offices and retail stores. We focus primarily on electrical end uses including cooling, ventilation, lighting, cooking, refrigeration, water heating, office equipment, and miscellaneous equipment. The hourly load shapes are aggregated to produce twelve monthly load shapes for three-day types (peak, standard, and non-standard) and integrated to produce annual EUIs.

Reference

Akbari H, Rainer L, Eto J. *Integrated Estimation of Commercial Sector End-Use Load Shapes and Energy Use Intensities in PG&E Service Area.* Lawrence Berkeley Laboratory interim report, 1991.

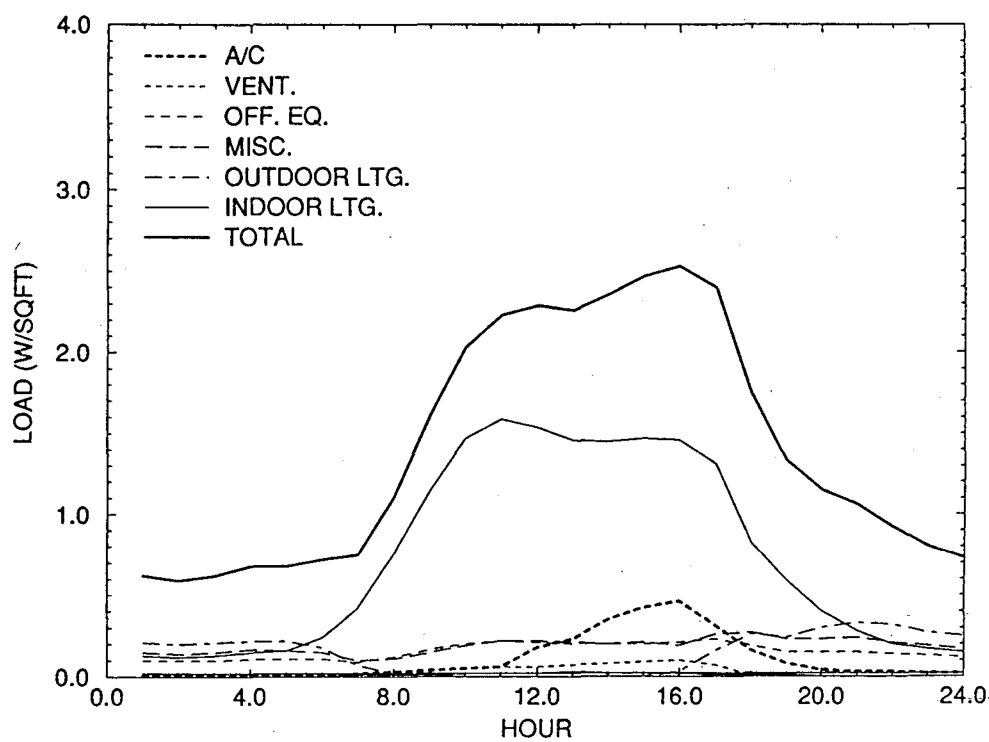

Figure *Reconciled average annual load shapes for end uses (air conditioning, ventilation, office equipment, miscellaneous equipment, outdoor lighting, and indoor lighting) in small office buildings in Northern and Central California (coastal climate zones). Indoor lighting in small offices contributes the most to the whole-building load shape and EUI. Air conditioning has an impact mainly on summer afternoon periods.*

The Impact of Variations in Building Parameters and Operating Conditions on Commercial Building Energy Use and Load Shapes

Y.J. Huang, H. Akbari, L. Rainer, and R. Ritschard

LBL has developed a database of load shapes and energy use intensities for 481 prototypical commercial and multi-family buildings in twenty major city markets as part of a Gas Research Institute (GRI) project to assess the potential of cogeneration in those building sectors. The creation of this database involved 1) estimating the number and sizes of buildings by class type, location, vintage, and equipment, 2) developing prototypical buildings for each category, and 3) performing DOE-2 computer simulations for these prototypical buildings. The building types covered were hospitals, schools, prisons, hotels, restaurants, offices, supermarkets, apartments, and retail stores. The completed database is available from GRI in electronic format both as DOE-2 input files and output files of hourly building loads (heating, total and latent cooling), electricity use (air-conditioning and non-air-conditioning), outdoor temperature, and humidity ratio.

In 1992, we will conduct a follow-on assessment and analysis of this large database to better understand the impact of variations in operating conditions on the load shapes of commercial buildings. In designing the original database, we disaggregated the commercial building stock into hundreds of subsectors and then represented each of these with a prototypical building, capturing the average physical and operational conditions of that sector. In reality, there are significant variations in end-use intensities, operating hours, building size, etc., within each of these building sectors. The 1992 analysis will use variational analysis to study how differences in the characteristics and operating conditions in commercial buildings can affect their load shapes and energy demand. We will then develop procedures to account for these variations when estimating sector-wide load shapes or the market potentials of different buildings-related technologies. Another project activity will be to put the databases of hourly loads for prototypical residential as well as commercial buildings that have been developed by LBL over the past five years onto floppy disks. This will make the databases easier to distribute and more accessible to other researchers.

Reference

Huang YJ, Akbari H, Rainer L, Ritschard RL. *481 Prototypical Commercial Buildings for Twenty Urban Market Areas (Technical documentation of building loads database developed for the GRI Cogeneration Market Assessment Model).* Gas Research Institute Report No. GRI-90/0326, April, 1991.

Use of Energy Management and Control Systems to Monitor Building Performance

H. Akbari and K. Heinemeier

Major energy conservation retrofit and demand-side management (DSM) programs are now being conducted across the nation, with increased emphasis on program evaluation. Monitoring of building energy performance—an important part of this evaluation—can include acquisition of facility or whole-building utility data, hourly whole-building data, and hourly submetered data. Most data are collected by dedicated monitoring equipment installed for the project.

Dedicated monitoring equipment must include various types of devices (Table). Sensors are needed to measure the required quantities, and wiring must be installed to connect the sensors to the datalogger. The datalogger includes software to sample, condition, average, and store the data. Also needed are storage devices: short-term, volatile memory, and possibly a permanent storage device such as a magnetic tape drive. The data can often be retrieved remotely, requiring a modem and software for downloading the data. All of this equipment—hardware and software—must be purchased, installed, and tested.

Most installed energy management and control systems (EMCS's) include the same devices listed above. As the Table shows, an EMCS usually has a large number of sensors; sophisticated interconnections between sensors, actuators, and processors (often comprising a local area network); a powerful processor capable of extensive computation; extensive memory; a large variety of available peripheral storage devices; and a modem with communications capabilities. Because equipment required for monitoring is likely to be present at an EMCS site, using it in a monitoring project would seem advantageous.

We used three college campuses in Texas as case studies to investigate how EMCS's currently in place can be applied to remote monitoring. We evaluated the entire process of obtaining data from the sites according to several different criteria, and recommended changes to enhance the usefulness of this technology.

We found that EMCS's can be used for monitoring energy performance. A wealth of information on building operation can be accessed without installing additional software or hardware. Relatively minor modifications to the available EMCS software could greatly improve this method of collecting data, in particular, EMCS software should be modified to allow averaging of data over one-hour intervals, to report data reliably at the end of each hour, to create concise and consistent formats for requesting and reporting data, and to create simple means of rapidly and reliably displaying or transmitting the data.

However, owing to the absence of protocols for this type of monitoring, and the fact that EMCS's are not designed with remote energy monitoring in mind, individual sites present unique problems and often require unique solutions. Before many of the benefits of EMCS-based monitoring can be realized, standardization must take place and specifications must be defined. In the coming year, we will be working to identify and outline such specifications.

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Heinemeier K, Akbari H, Claridge D, Haberl J, Poynor B, Belur R. *The Use of Energy Management and Control Systems for Retrofit Performance Monitoring in the LoanSTAR Program.* Lawrence Berkeley Laboratory Report No. LBL-31144, 1991.

Heinemeier K, Akbari H. Evaluation of the use of energy management and control systems for remote building performance monitoring. In: *Proceedings of the ASME International Solar Energy Conference, Maui, HI, April, 1992.* Also published as Lawrence Berkeley Laboratory Report No. LBL-31273, 1992.

Table *Advantages (+) and disadvantages (-) of dedicated and EMCS-based monitoring.*

		Dedicated Monitoring		EMCS Monitoring
Sensors	-	Must be purchased	+	Existing
	-	Must be installed	+	Numerous points
	+	Researcher can select type	-	Used for building control
	+	Researcher can select accuracy	-	May have to add required sensors
	+	Researcher can calibrate	-	Accuracy and calibration not under researcher's control
Connections	-	Must be purchased	+	Existing
	-	Must be installed	+	Sophisticated networking
	+	No other traffic	-	Other traffic can interfere with monitoring
	+	Can be sized for monitoring	-	Monitoring traffic can interfere with operation
			-	Must be added if expansion needed
Data Logging Processor	-	Must be purchased	+	Existing
	-	Simple processor	+	Sophisticated processor
Data Logging Software	-	Must be purchased	+	Existing
	-	Simple sampling, conditioning, averaging	-	Often simple sampling, conditioning, averaging
	-	Predefined	-	Often predefined
	+	Appropriate for monitoring needs	-	Not defined for monitoring needs
			+	Can be sophisticated computation or calculation
Data Storage	-	Must be purchased	+	Existing
	-	Usually limited size	-	Sometimes must be supplemented
			+	Both short and long term
			-	Sometimes size limitations
Modem	-	Must be purchased	+	Existing
	+	Dedicated to researcher	-	Also use by operator, vendor

Thermal Energy Storage Systems: Case Studies for Evaluating and Verifying System Performance

H. Akbari and O. Sezgen

We developed two case studies for reviewing and analyzing energy performance of thermal energy storage (TES) in commercial buildings. Our case studies considered two partial ice storage systems in Northern California. For each case, we compiled historical data on TES design, installation, and operation. This information was further enhanced by data obtained through interviews with the building owners and operators. The performance and historical data were categorized in groups related to TES and to non-TES components; the TES group was further divided into subgroups related to design, installation, operation, and maintenance of the system.

An integral objective of our study was to analyze the measured energy performance of TES systems and to compare TES performance with "conventional" cooling systems. We compared the energy performance of TES systems with three conventional systems: a conventional system with a single chiller, a split system with two smaller chillers of equal capacity, and a split system with two unequal chillers (one twice the capacity of the other).

Table 1 presents a summary of our comparisons for the two case studies. We selected a summer week for the first case and a winter week for the second case for these comparisons. In both cases, TESs saved power and energy during the peak period. However, the total weekly energy use of TES systems was much higher than those of the conventional systems. Mainly because of the lower coefficients of performance of the chillers when they are making ice (about 40% lower), and the inefficiencies of iced-water/chilled water loop heat exchangers in the TES systems.

Table 2 summarizes the historical operational and maintenance problems with the case-study TES's. In both cases, significant differences exist between the designs intended and the systems as installed. In addition, both systems had undergone major trouble shooting periods. Initial complications included problems related to both TES and non-TES components and equipment. Based on the information obtained from these case studies, conventional systems logically be assumed to have as many initial and operating problems as TES systems; however a failure in a TES system is likely to have a more dramatic impact on thermal comfort and electricity charges. Conventional and TES systems alike could benefit from a detailed commissioning and performance accepting tests.

Reference

Akbari H, Sezgen O. *Case Studies of Thermal Energy Storage (TES) Systems: Evaluation and Verification of System Performance.* Lawrence Berkeley Laboratory Report No. LBL-30852, 1991.

Table 1 *Savings in Electricity Use and Peak Demand Due to the Existing TES System Compared to Conventional Chilled-Water Systems.*

Configuration	Weekly Savings with TES: On-peak MWh	Part-peak MWh	Off-peak MWh	Total kW	Total %	Peak Cooling Reduction kW	Peak Cooling Reduction %
Case 1: a summer week (3rd week of August 1990)							
Single Chiller	15.0	0.3	-35.8	-20.5	-20	640	54
Split Chiller	16.9	-3.5	-51.0	-37.6	-43	780	59
Two Chillers[1]	13.5	-4.9	-55.8	-47.2	-63	660	54
Case 2: a winter week (3rd week of February 1987)							
Single Chiller	4.7	-0.2	-5.3	-0.8	-7	140	47
Split Chiller	2.6	-0.9	-5.4	-3.7	-45	10	6
Two Chillers	2.8	-0.6	-5.3	-3.1	-35	20	11

[1]One chiller twice the size of the other.

Table 2 *Operational and maintenance problems identified in two thermal energy systems (TES) case studies.*

	Case 1	Case 2
DESIGN		
Storage Sizing	X	X
Distribution System Sizing (1)		X
Condenser Sizing (1)	X	
Evaporator Sizing (1)		X
Environmental Changes (1)	X	
Changes in Load Levels (1)	X	X
Rules and Regulations (1)	X	
Isolation of Sections for Maintenance (1)	X	
Refrigerant Storage for Maintenance (1)		X
Extra Capacity for Maintenance		X
Improper Layout (1)	X	
Oil Recovery (1)	X	X
Provisions for Future Expansion (1)	X	X
INSTALLATION		
Cleaning After Construction (1)		X
Proper Acceptance Testing (1)	X	n/a (2)
OPERATION		
Control System (1)	X	X
Expansion Valve Setting (1)		X
Time Clock		X
Use of All of the Ice Capacity	X	
Compressor Failures (1)	X	X
Refrigerant Leaks (1)	X	X
Ice Thickness Control		X
Overcharging		X
Bridging of Ice Fields		X
Maintaining Chilled Water Design Temperature (1)		X
Oil Contamination (1)	X	X
Balancing Fluid level in Tanks	X	
Comfort Level During a Peak Day (1)		X
MAINTENANCE		
Performance Monitoring+Sensor Calibration (1)	X	X
Water Filtration (1)		X
Service and Spare Parts	X	
Substandard Quality of Material and Equipment (1)	X	
Accessibility of Equipment (1)		X

(1) These problems are not unique to TES systems; they can occur in conventional systems as well.
(2) Data not available.

The Energy and Comfort Performance of Evaporative Coolers for Residential Buildings in California Climates

Y.J. Huang, H.F. Wu, and J.W. Hanford

The use of evaporative coolers is an energy-conserving alternative to air-conditioning that is particularly suited to the semi-arid climates of California. Because they require power only to drive fans and pumps, evaporative coolers consume far less electricity than do air conditioners.

Our continuing project investigates the applicability of evaporative coolers in residences and small commercial buildings in California using computer models, field measures, and surveys of existing installations. The computer model indicates that, for a house in Pasadena built according to current energy standards, a direct evaporative cooler will produce undesirable humidity levels during peak cooling times, but a two-stage indirect/direct cooler can maintain comfortable temperatures and humidities at all hours (Figure). The amount of water consumed by evaporative coolers is a justified concern for drought-plagued California; comparing the computer calculations of water consumption to what a typical household uses, an evaporative cooler will add about 4-10% to the household water consumption for the year, but the water usage during the peak summer months may increase by as much as 30% (Table).

A survey of engineers and contractors around the country produced very positive responses: two of 19 expressed dissatisfaction with the indoor humidity; one of 24, with high noise level. Most of these installations were influenced by the lower operating costs for evaporative coolers and by the previous experience of the engineer or contractor. Despite the better performance of the two-stage evaporative coolers, a phone survey of California distributors and contractors indicated that over 95% of the units being installed are still simple direct coolers. Due to the absence of design guidelines and uncertainty about their performance, these evaporative coolers are regarded as auxiliary spot coolers installed in tandem with standard air-conditioning.

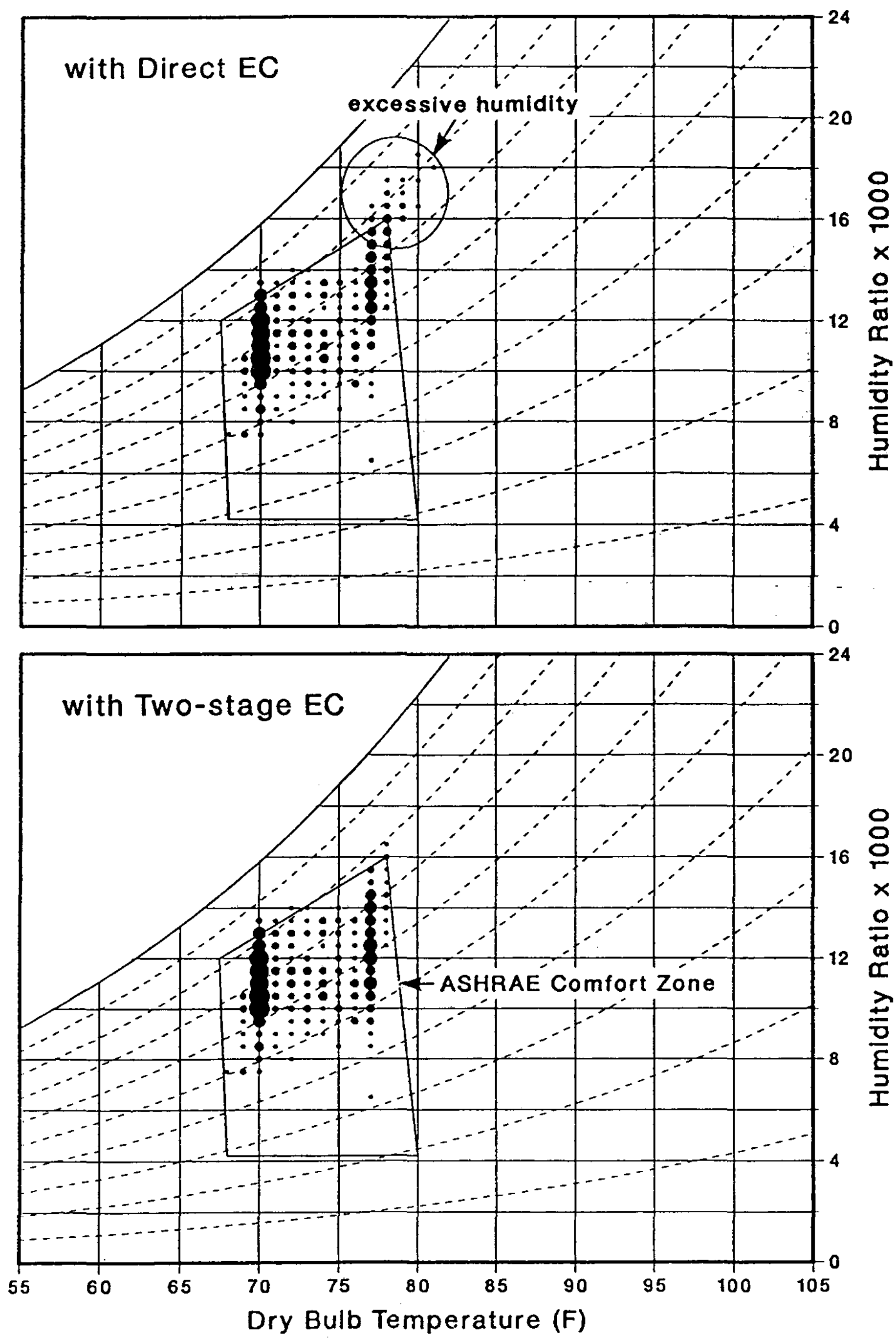

Figure *Results of computer modelling show August indoor temperature and humidity for a house in Pasadena, CA. EC = evaporative cooling*

Reference

Huang YJ, Hanford JW, Wu HF. *A Preliminary Evaluation of the Performance, Water Use, and Current Application Trends for Residential Evaporative Coolers in California Climates.* Draft Final Report to the California Institute for Energy Efficiency, Lawrence Berkeley Laboratory, 1991.

Table

*Results of computer modelling show water consumption in houses built according to Title 24 standards.**

(gallons per day)

	Direct with AC Backup		Two-Stage Stand-alone	
Location	Annual Average	Peak Month	Annual Average	Peak Month
Santa Rosa	6	20	9	41
Pasadena	4	14	5	18
Riverside	8	42	11	62
Fresno	11	39	18	73

* Total household water use: 108/person, 214-523/household

Opportunities for Energy-Efficiency Improvements in HUD-Assisted Housing

R.L. Ritschard, R. Diamond, and J.A. McAllister

A primary goal of the U.S. Department of Housing and Urban Development (HUD) is expansion of home ownership and of affordable housing opportunities. Recognizing that energy efficiency can play a significant role in an affordable-housing strategy, HUD and DOE established a DOE-HUD Initiative on Energy Efficiency in 1989 to improve the energy efficiency of HUD-assisted housing and to make it more affordable. The specific objectives are to apply existing technical information on energy efficiency developed by DOE and by other federal, state, and local public and private organizations to HUD-assisted housing construction and to support retrofit activities. It is expected that the DOE-HUD initiative will lead to annual savings of 0.15 quad (150 trillion Btus) per year or nearly $1.5 billion in annual energy costs within the buildings sector after a 10-year implementation period.

The DOE-HUD initiative follows four strategic steps:

- prioritization of targeted HUD programs;
- development of technical linkages between DOE, HUD, and other private and public sector organizations;
- dissemination of information to personnel responsible for implementing HUD-funded programs;
- revision of energy-related guidelines for certain HUD programs.

LBL has been involved in studies of HUD's public housing for nearly eight years and has published many technical papers on this subject. A key research area identified in those studies was the effectiveness and persistence of energy savings from conservation measures installed in public housing. For example, in some cases energy and cost savings decreased after the first post-retrofit year. As part of the DOE-HUD initiative, we have collected new data on energy use in public housing apartments for two to three years after retrofit. These data are being analyzed and compared to the pre-retrofit and first year of post-retrofit data to determine if the initial energy savings persisted. Other HUD programs that provide federal assistance to private investors, property owners, nonprofit corporations, and other organizations for low-income multifamily housing are also being studied.

During this fiscal year, we also evaluated the energy and cost savings of 350 units of low-income, multifamily housing (Section 8 federally-subsidized rental housing) in Vermont that had switched its heating fuel use from electricity to natural gas. Source energy (i.e., energy from the power plant) decreased significantly as a result of the fuel switch during the first post-retrofit year, especially on the coldest days (Figure, see next page). More important, the annual energy costs paid by the tenants were also greatly reduced, thereby making these apartments more affordable.

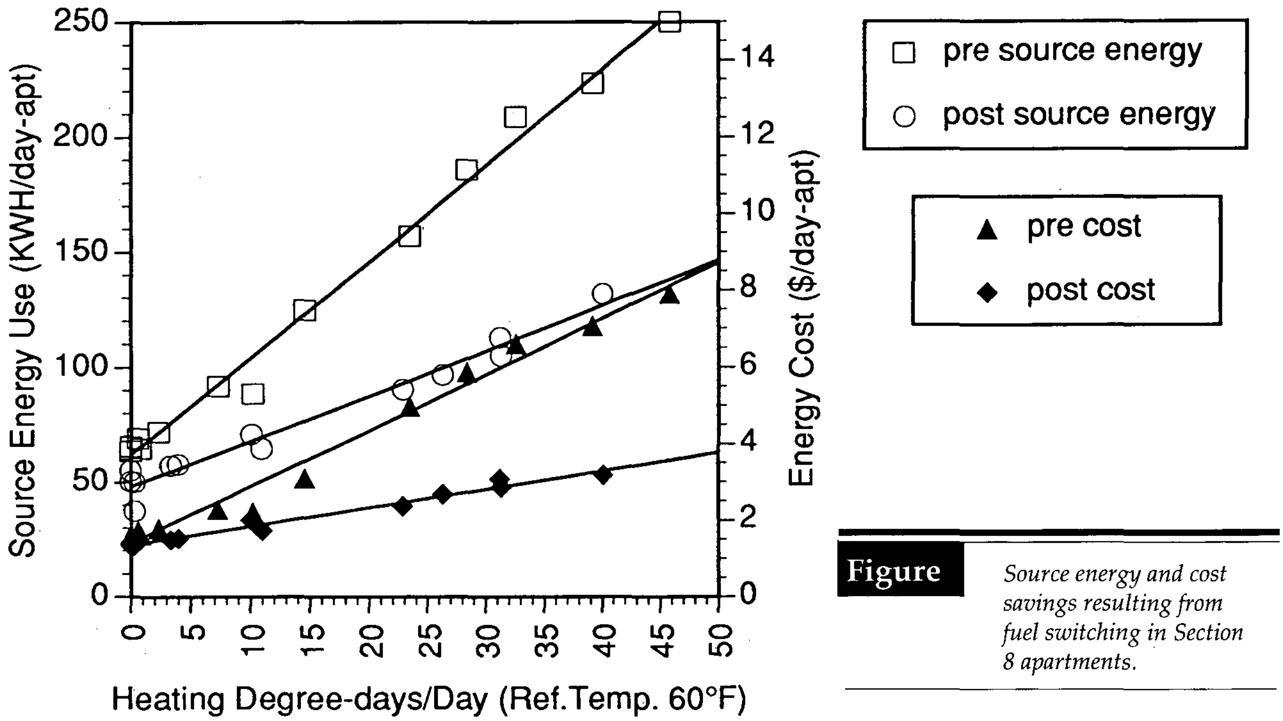

Figure *Source energy and cost savings resulting from fuel switching in Section 8 apartments.*

Peak Power and Cooling Energy Savings of Trees and White Surfaces in Sacramento, California

H. Taha and H. Akbari

The direct effects of high-albedo coatings and increased vegetation were examined by monitoring the outdoor and indoor microclimates and cooling energy use in several buildings in Sacramento, California. Six occupied houses and one school building were fully instrumented for this purpose, and variables were logged every ten or twenty minutes during September and October of 1991. The variables included

- solar radiation on vertical and horizontal surfaces;
- surface temperature at several outside and inside points such as roofs, external walls, ceilings, attics, and interior walls;
- indoor and outdoor air temperatures;
- air conditioner supply and return temperatures;
- indoor and outdoor relative humidity;
- wind speed;
- wind direction;
- soil moisture at two levels;
- sub-soil temperatures at three levels;
- air conditioner energy use.

Sites were categorized either as albedo cases or vegetation cases. In one case, a house that had an initial albedo of 0.18 increased to 0.77 after whitening with an elastomeric roof coating. With the white roof, there was no cooling electricity used in the house, except for a few hours of higher occupancy, during which the thermostat setting was lowered from 26°C down to 23°C. In practical terms, therefore, whitening the roof eliminated almost all the cooling-energy needs of the house during September (a particularly hot month) and October (Figure 1).

In another case, we instrumented a house that had no trees on the south and west sides. Two small trees (in pots) were positioned along the west wall so as to partially shade two windows and the middle area of the wall. A third small tree was positioned near a south window. Each tree was about 2.3 m tall, 1.5 m across, with the leaves starting at a height of about 1.5 m above the ground. Figure 1b shows the air conditioning electricity use before and after positioning the trees. The linear fits indicate savings of approximately 40% in electricity at ambient temperatures around 40°C.

Reference

Akbari H, Huang J, Sailor D, Taha H, Bos W. *Monitoring Peak Power and Cooling Energy Savings of Shade Trees and White Surfaces in the Sacramento Municipal Utility District (SMUD) Service Area.* Interim Report prepared for the California Institute for Energy Efficiency and SMUD, Lawrence Berkeley Laboratory, 1991.

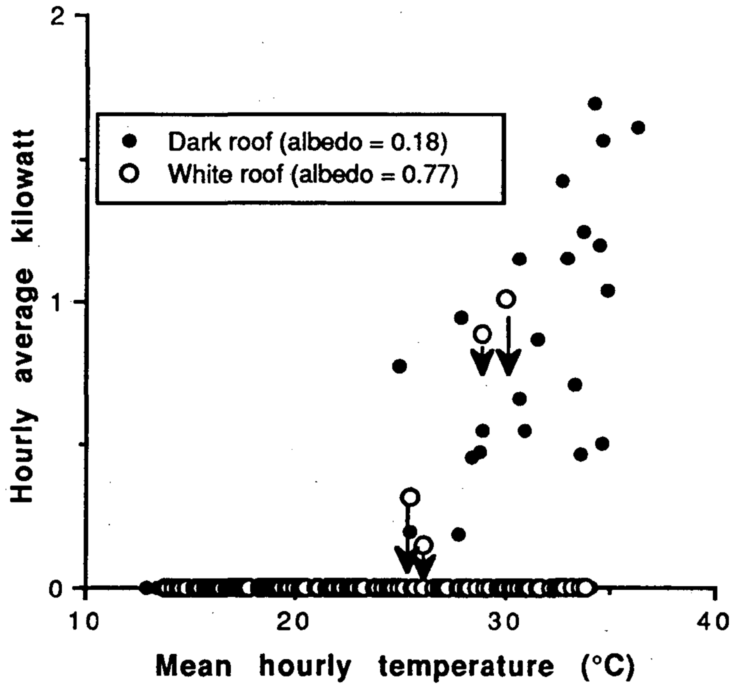

Figure 1a *Cooling electricity use in a house before and after whitening the roof.*

←

Figure 1b *Cooling electricity use before and after planting two small trees on the west and one tree on the south of a house.*

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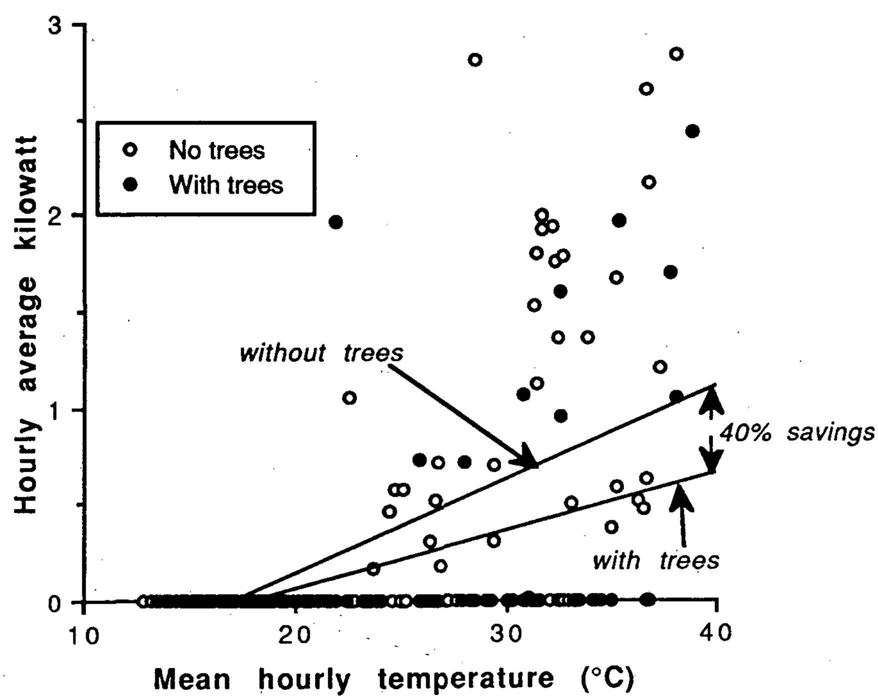

Case Studies of Energy Use in Industrial Buildings

H. Akbari and O. Sezgen

Energy use patterns in many of California's fastest-growing industries are not typical of the existing mix of industries elsewhere in the United States. Many California firms operate small- and medium-sized facilities, often in buildings used simultaneously or interchangeably in time for commercial (office, retail, warehouse) and industrial activities. In the industrial subsectors, the energy required for "building services" to provide occupant comfort and necessities (lighting, HVAC, office equipment, computers, etc.) may be at least as important as the more familiar process energy requirements—especially for electricity and on-peak demand. Electricity for these building services is sometimes priced as if it were base-loaded, like process uses; in reality, this load varies significantly according to occupancy schedules and cooling and heating loads, much as in a commercial building.

Using informal field surveys, simulation studies, and detailed analyses of existing data (including utility commercial and industrial audit files), we have studied the energy use in this important but largely neglected subsector through a multi-step procedure: 1) characterizing non-process building energy and power use in California industries; 2) identifying conservation and load-shaping opportunities in industrial building services; and 3) investigating industrial buildings and system design methodologies. We have addressed the above issues by performing an extensive survey of the existing publicly available data, characterizing and comparing the building energy use in this sector, and by closely examining and analyzing energy use in two industrial case-study facilities in California. Based on the information obtained for the selected case studies, we have also assessed the design consideration for these industrial buildings, characterized their energy use, and reviewed their conservation and load-shaping potentials.

The study has concluded that the lighting and HVAC energy-use characteristics of high-technology industries (as represented by our case-study buildings) and their conservation potentials are very much comparable to those of office buildings. Simulating the impact of conservation measures commonly recommended for office buildings, we estimate that more than 50% of electricity and gas use for the building services in the two case-study facilities can be saved (Figure). Case studies in other regions and for other important industries can provide useful information to better understand the energy use patterns and the impact of conservation and load-shaping measures on the industrial loads.

References

Akbari H, Borgers B, Gadgil A, Sezgen, O. *Analysis of Energy Use in Building Services of the Industrial Sector in California: A Literature Review and a Preliminary Characterization.* Lawrence Berkeley Laboratory Report No. LBL-29749, 1991.

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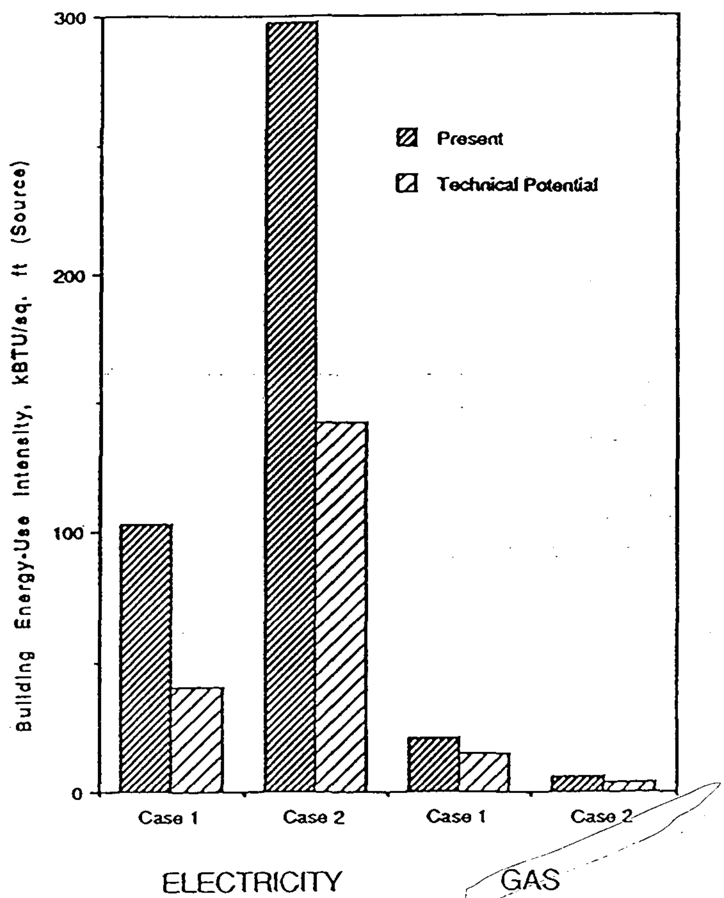

Figure *Technical potential for energy conservation for industrial case-study buildings.*

BUILDING ENERGY DATA

Energy Use and Savings from the Energy Edge Buildings

R. C. Diamond, M. A. Piette, B. Nordman, O. de Buen, and J.P. Harris

The 28 buildings in the Energy Edge Program provide unique opportunities for studying the energy performance of new commercial buildings in the Pacific Northwest. In the past year, we have focused primarily on the results of the data analysis, and, to a lesser degree, on the analysis methodology. We investigated three questions:

•How does the actual energy use compare to the predicted values?

•How do these buildings compare to other new buildings in the region?

•How do these buildings change over time?

We addressed these questions by examining the utility billing data for the buildings (in some cases, up to four years of records), the hourly sub-metered end-use data for ten buildings, and the output from simulation models. We examined such indices as lighting and equipment power densities versus end-use consumption, and analyzed the implications for standards and code compliance. We also analyzed the savings attributable to the energy conservation measures themselves through direct analysis of the monitored data and from the output of the simulations, comparing the predicted and "actual" performance of the measures and investigating reasons for the differences.

A key finding was that while the buildings are using roughly 10% more energy than predicted, they are consuming 30% less energy than is being used by typical new construction in the region. Moreover, eight Energy Edge office buildings are using nearly 50% less energy than is being used by other new office buildings for which we have comparable data (Figure). In reviewing the results for 20 categories of energy conservation measures, we examined such issues as the difficulties in defining baseline conditions and the problems in simulating certain strategies (e.g., HVAC and daylighting controls). Finally, we suggested simplified approaches that could be used in the next generation of commercial building research, demonstration, and design-assistance programs.

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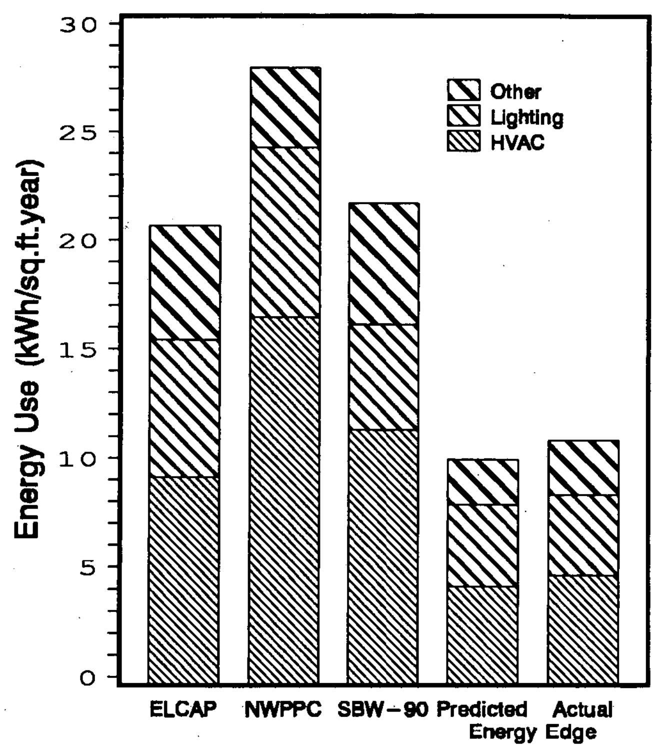

Figure *End-use energy consumption for eight Energy Edge office buildings with comparison buildings. ELCAP data are from 14 post-1980 all-electric buildings. NWPPC are the 1989 forecast numbers from the Northwest Power Planning Council for new construction in the Northwest. SBW-90 are prototypes developed for the region derived from 1989 current practice with Seattle weather.*

Measured Energy Use of Refrigerators in the Laboratory and in the Field

A.K. Meier

Residential refrigerators consume about 7% of the total electricity used in the United States and are therefore the target of numerous efficiency improvements. As new technologies are tried, the details of the energy test procedure (as performed in the laboratory) become increasingly important. We compared the results of two major international test procedures: the U.S. DOE and Japan's JIS. Each has unique features of its own, such as ambient temperatures, door openings, defrost conditions, etc. A consequence of these differences is that technical innovations considered in one refrigerator cannot be compared to another tested with the other procedure.

Twenty-four domestic refrigerators were tested. The JIS tests yielded energy consumptions on average of about 15% less than the DOE tests (Figure 1). The difference was negligible for smaller units and those using less energy. The DOE test was roughly 20% higher for side-by-side units. Various features of the JIS test, such as door openings, appear to offset the higher ambient temperatures required by the DOE test.

Field consumption of refrigerators also needs to be periodically compared to the test procedure. The Buildings Energy Group maintains the largest database of measured energy use of refrigerators. The field electricity use of 209 refrigerators was compared to their labeled consumption (Figure 2). The mean field use of all units was 1009 kWh/year, 882 kWh/year for top-freezers, and 1366 kWh/year for side-by-sides. There was considerable scatter in the results but, in general, the label overpredicted field use; for a typical unit with a labeled use of 1160 kWh/year, the field use was about 15% lower.

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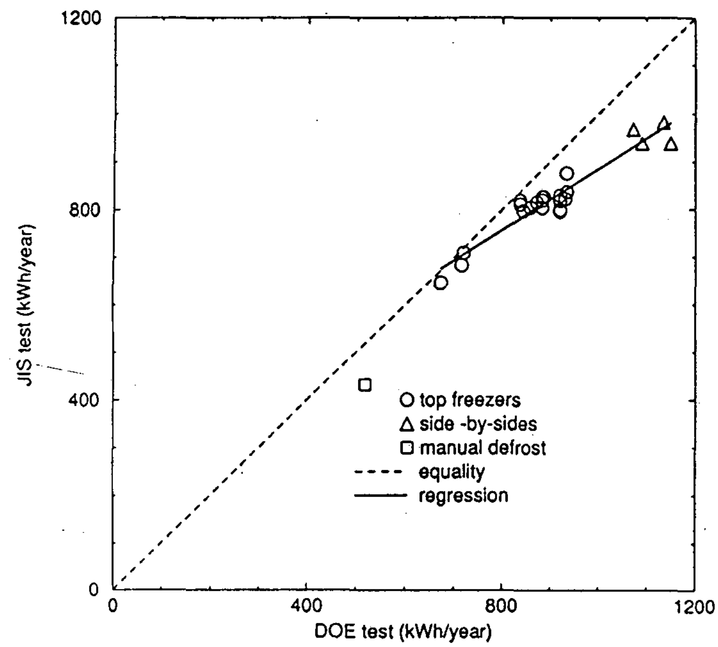
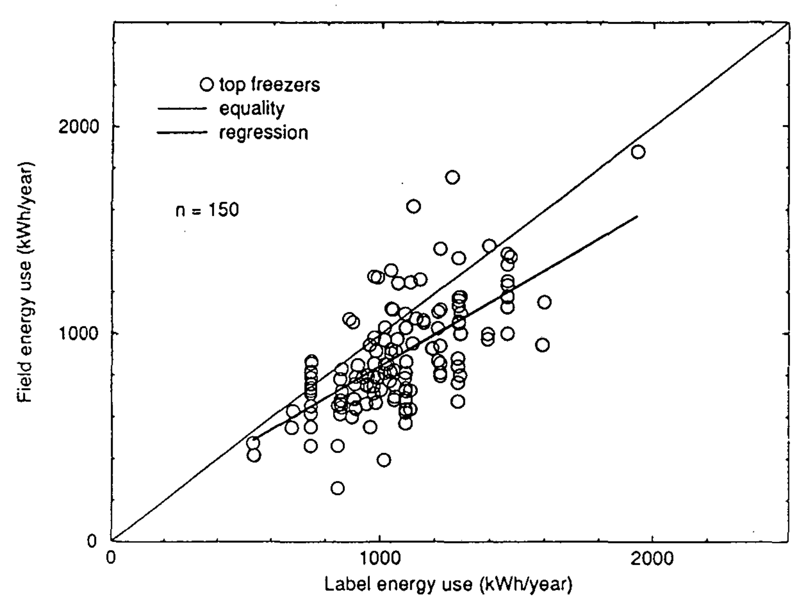


↑ **Figure 1** *Energy use as measured by the DOE and JIS test procedures.*



→ **Figure 2** *Labeled versus field energy use for top-freezer refrigerators.*

Office Equipment Energy Use and Trends

M.A. Piette, J.H. Eto, and J.P. Harris

To improve current estimates of the energy use of office information technologies, we have developed a spreadsheet model based on current utility surveys and equipment-monitoring studies.

Office information technologies are using an increasing amount of electricity energy in commercial buildings and are often considered to be the fastest growing electric end-use. We have developed a spreadsheet model to estimate current and future energy use by office equipment. Seven categories of equipment—mainframe- and minicomputers, personal computers (PCs), printers, video display terminals (VDTs), photocopiers, facsimile machines, and electric typewriters—are examined for 11 types of commercial buildings. The energy use of office equipment is a function of the nameplate power rating, average power as a percent of the nameplate rating, hours of use, and diversity of use during the hour. Primary sources of data include utility onsite surveys, monitoring studies, and industry sales projections. Equipment-monitoring studies have shown that the average power use is often much less than the nameplate power.

We estimate that the energy used by office equipment grew faster in the 1980s than it will in the 1990s and beyond. Office equipment energy use will be dominated by mainframe- and minicomputers during the 1990s, with PCs representing a growing fraction of energy use in the 1990s and beyond. Printer energy use is also expected to grow rapidly. The total energy use by office equipment in the office buildings ranges from 1.0 kWh/ft^2-year in 1983 to 4.2 kWh/ft^2-year in 2011. We find that the fraction of energy used by office equipment appears to be growing, ranging from 5.8% in 1989 to 10.9% by 2011.

Future enhancements to the spreadsheet model will include incorporating new data sets from recent survey and monitoring projects, updated equipment definitions, and scenario analysis of possible futures, including a high-efficiency scenario.

Reference

Piette MA, Eto JH, Harris JP. *Office Equipment Energy Use and Trends.* Lawrence Berkeley Laboratory Report No. LBL-31308, September 1991.

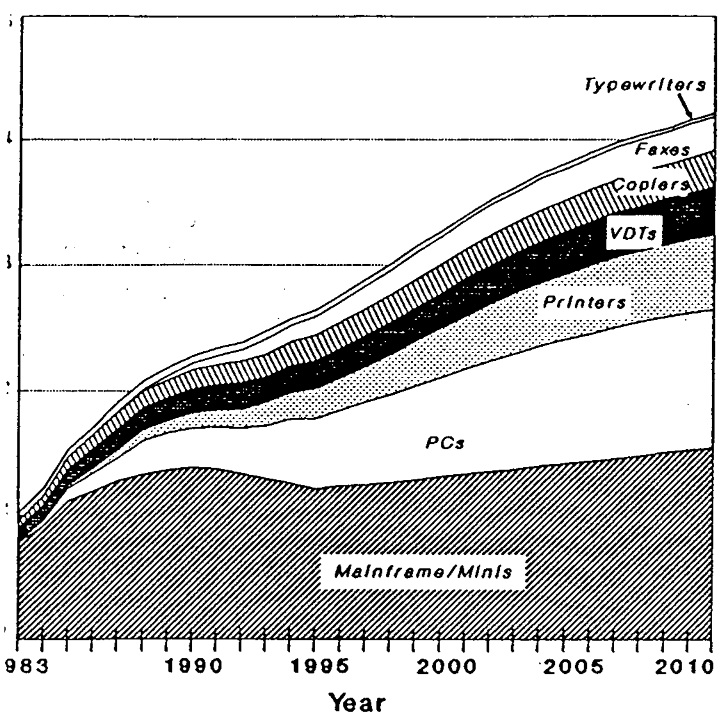


Figure *Annual office equipment energy-use intensity (EUI) for office buildings. The growth in number (saturation) and unit nameplate power ratings (W/unit) of the PC and printer equipment dominate the growth in the EUI.*

Stimulating Utilities to Promote Energy Efficiency: The Madison Gas and Electric Competition

E. Vine, O. de Buen, and C. Goldman

In the past year, LBL conducted the process evaluation of the Energy Conservation Competition Pilot (the Competition), a program authorized by the Public Service Commission of Wisconsin (PSCW) to encourage the Madison Gas and Electric Company (MGE) to promote energy efficiency among its customers. The two key objectives of the Competition were to motivate MGE to improve its conservation efforts in terms of both the quantity and cost-effectiveness of conservation achieved, and to provide an opportunity for energy service companies to design and implement innovative and competing programs. The PSCW also approved this program in order to test whether the Competition format was a regulatory strategy that should be used for other Wisconsin utilities for pursuing conservation.

During the Competition, MGE offered conservation programs of its own design to three targeted customer sectors: small commercial and industrial, large commercial and industrial, and the residential rental (multifamily) sector. Simultaneously, three other firms chosen through a competitive bidding process offered their own conservation programs, each targeted to one of the three sectors. In each sector, MGE and its competitor vied to provide conservation services to the same group of customers. At the end of the Competition, the competitor achieving the most energy conservation cost-effectively in each sector received a cash incentive (bonus).

In the process evaluation, we found the MGE Competition to be an innovative experiment and to have been generally successful in stimulating utility and third-party delivery of demand-side management (DSM) services at MGE in the short term, assessing market potential, encouraging innovative DSM program delivery strategies, and providing a measure of utility performance (net benefits). For example, the Competition demonstrated to the PSCW, MGE, and other utilities the amount of energy conservation that could be achieved in certain sectors over a specified time period (9-12 months), and the results of the Competition will be used by the PSCW as a yardstick for measuring and comparing the performance of utilities in Wisconsin.

Our evaluation suggests, however, a significant divergence of opinion among key participants about the relative merits of this approach. The PSCW staff viewed the experiment as highly successful in terms of motivating MGE and other Wisconsin utilities to increase conservation services, MGE staff were not enthusiastic about the basic approach, and other utilities reacted negatively. Despite the Competition's problems and limitations, the program clearly stimulated MGE to develop a broader menu of conservation services for its customers and to implement these programs more aggressively.

Competition is one of several approaches that can be used by PUCs to stimulate the provision of energy conservation services. The appropriateness of each option—or of combining several approaches—will depend to a great extent on a PUC's overall regulatory philosophy and policy objectives, PUC organizational capabilities (e.g., large vs. small staff) and approach (e.g., proactive vs. mainly reactive), and consideration of a utility's specific circumstances, problems, and preferences.

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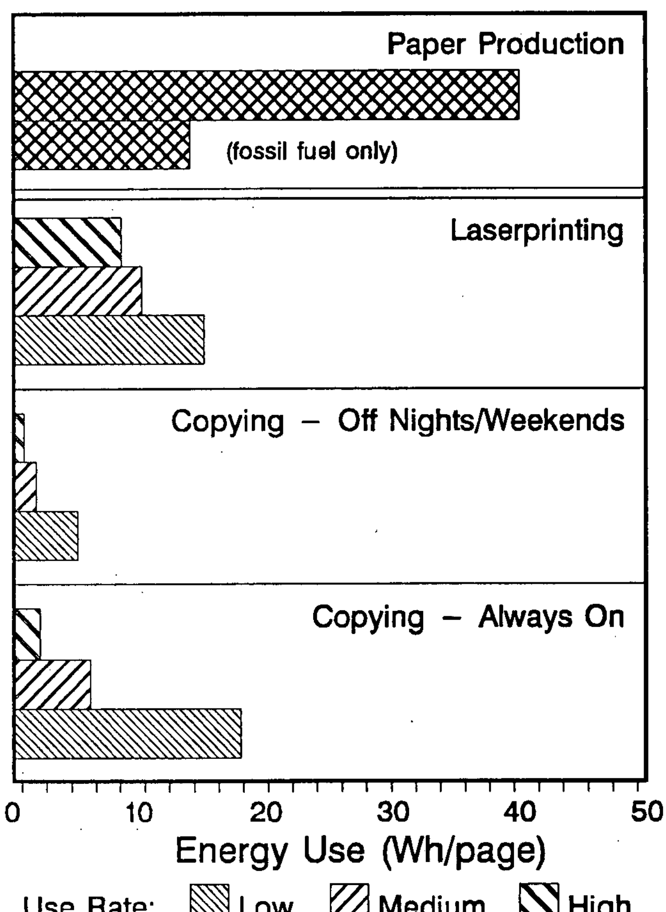
Applying Energy End-Use Analysis to Solid Waste

A. Meier and B. Nordman

Energy analysis today involves characterizing supply systems as well as the nature of energy demand. Energy policy takes into account supply and demand options, including whatever costs and benefits they entail. A similar relationship exists with materials production, use, and disposal, with energy supply resembling waste disposal and energy demand similar to materials use, or, waste production. Each case involves processes of preparing and providing resources to people, and the processes by which these resources are usefully consumed. Good policy relies on understanding the entire system and the full range of available options.



Municipal solid waste (MSW) disposal (such as landfilling, recycling, and incineration) is relatively well understood. In contrast, waste production is poorly understood and is rarely discussed. Solid-waste policies focus almost entirely on disposal and usually give only limited attention to production options. Our research suggests that this asymmetry is not caused by fundamental differences between the two problems, but because energy analysis is more mature and has developed the necessary ways of analyzing and measuring consumption.

The key product of our project is development of the analogy between energy and materials (waste). Important aspects of the project include conceptual, economic, institutional, historical, and environmental linkages. Applying energy end-use analysis to solid waste is a critical concept that requires breaking down waste production into material end-uses such as eating, clothing, housing, transportation, health care, information, and entertainment. We are producing a breakdown of MSW according to these categories, as well as examples of "materials efficiency measures" with costs and material benefits.

Paper imaging illustrates the interaction between energy end uses and materials end uses. The figure shows the amount of energy used to make one image, which consists of the energy of paper production and the energy used by the imaging equipment (i.e., laserprinting or copying). The energy invested in paper production is much larger than the energy used in the imaging process, and measures to reduce production energy (such as using both sides of a piece of paper) can have much more impact on energy use than efficiency improvements in the imaging equipment.

Figure *Source energy required to produce one piece of paper (total energy including wood waste and fossil-fuel component only) as well as the source energy to make one image on specific types of equipment. Standby energy use can dominate at low-use rates, whereas imaging energy can dominate at high-use rates; however, in all cases production energy is much greater than imaging energy.*

END-USE FORECASTING

Database of Information Relevant to Residential-Sector End-Use Forecasting

J. Hanford, M. Lecar, J. Koomey, J.E. McMahon, and M.D. Levine

In FY 1991, we began to compile data needed to improve forecasts of energy use in the U.S. residential sector. This effort represents an attempt to collect and document these data systematically and to incorporate them into a computerized database system. The ultimate purpose of the database is to serve as the source of data for models that forecast residential energy use and conservation potential.

The database will eventually include the following input data:

- baseline unit energy consumptions (UECs) of appliances and equipment;
- baseline appliance and equipment saturations;
- thermal shell characteristics of buildings;
- forecasted population and households;
- forecasted energy prices;
- different consumer choice algorithms;
- elasticities.

In FY 1991, we compiled estimates of UECs and created a preliminary database design. In FY 1992, we will continue this effort, analyzing the UEC data collected, and adding other input data from the above list.

In addition, the database will eventually include outputs from residential forecasting models, such as:

- total energy use by fuel;
- energy use by end-use;
- forecasted saturations, UECs, and energy factors.

Model inputs and outputs, as well as all other information in the database, will be fully documented with the source and an explanation of how they were derived. When complete, the database will be used as the source of input data for the residential forecasting models used in the Energy Analysis Program. Lessons learned in creating the residential database will be applied in future years to creating a database for commercial-sector forecasting.

The Potential for Efficiency Improvements in Residential and Commercial Buildings

J. Koomey, C. Atkinson, R. Brown, A. Meier, B. Atkinson, S. Boghosian, J. McMahon, and M.D. Levine

The first part of this project assessed the potential for improving the efficiency of electricity use in the U.S. residential sector. This potential is expressed in terms of cost (cents/kWh) and electricity savings (Terawatt-hours or TWh). The results are presented in a supply curve of conserved electricity (Figure 1).

The supply curve of conserved electricity consists of roughly 200 energy conservation measures, which fall into four distinct types:

- retrofitting of existing buildings and equipment;
- improving the thermal performance of new buildings and equipment;
- raising the efficiency of appliances as they are replaced;
- switching from electricity to natural gas.

The reduction in electricity use by the year 2010 is best shown in Figure 2. The cost-effective technical potential is about 400 TWh/year below the frozen efficiency baseline, which represents a reduction of approximately 40% .

The next phase of this project involves refining the supply curve in response to extensive comments from reviewers, extending the supply curve to cover natural gas end-uses, calculating achievable potential from the technical potential estimates, and creating a supply curve for U.S. commercial office buildings. These efforts were begun in FY 1991 and will continue in FY 1992.

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Koomey J, Atkinson C, Meier A, McMahon JE, Boghosian S, Atkinson B, Turiel I, Levine MD, Nordman B, and Chan P. *The Potential for Electricity Efficiency Improvements in the U.S. Residential Sector.* Lawrence Berkeley Laboratory Report No. LBL-30477, July 1991.

Figure 1 *A supply curve of conserved electricity. Each step represents a conservation measure. The height of each step is the measure's cost of conserved energy (cents/kWh), and its width is the estimated savings potential for that measure in the year 2010.*

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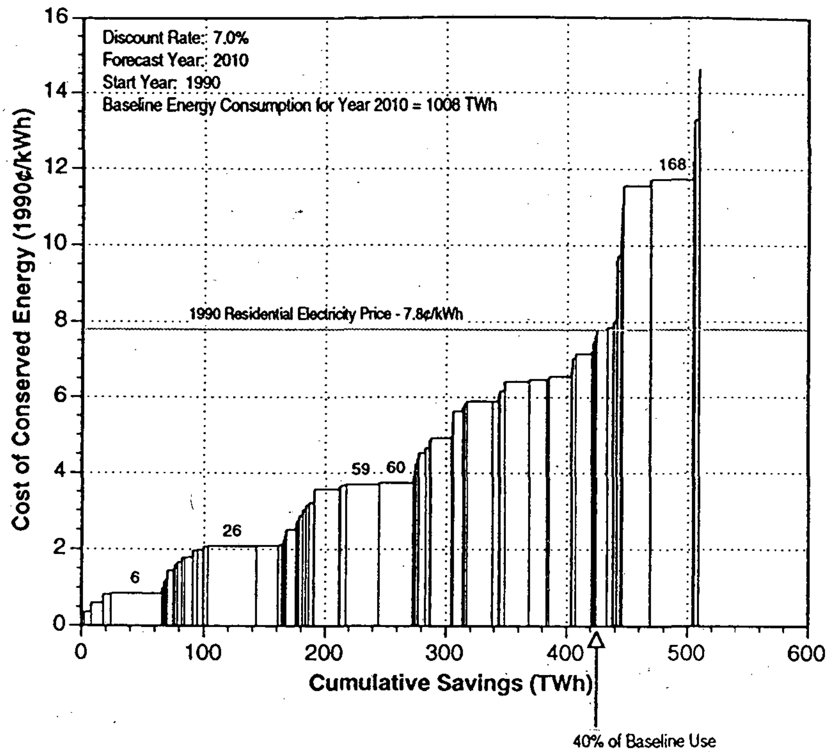

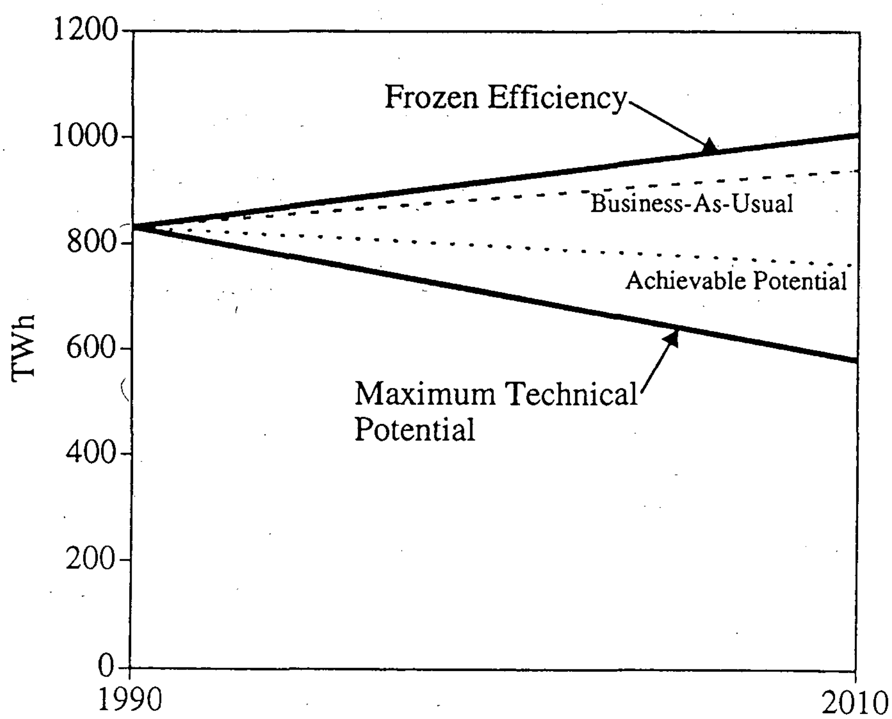

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Figure 2 *Electricity use over time for the baseline ("frozen efficiency") forecast, a "business-as-usual" forecast, the achievable conservation potential, and the technical potential. The conservation supply curves program currently estimates the frozen efficiency baseline and the maximum technical potential.*

An Engineering-Economic Approach to Assessing Future Energy Use and Carbon Emissions in U.S. Residences

J. Koomey, J. McMahon, M. Orland, F. Johnson, M.D. Levine, and P. Chan

Forecasting models have been used extensively to assess the effect of government policy initiatives on residential energy use. Such analyses have acquired greater urgency because of suggestions that greenhouse gas emissions from energy use may affect the global climate. Our ongoing research (to be completed in FY 1992) explores U.S. residential energy futures and their associated carbon emissions using a simplified representation of the electricity supply mix and a sophisticated end-use model that incorporates econometrically derived elasticities and engineering estimates of the cost of improving energy efficiency in appliances, space-conditioning equipment, and building shells.

This analysis draws upon the LBL Residential Energy Model (LBL-REM), a modeling framework that has been used since 1981 for analyses of appliance efficiency standards. The data in this model have been constantly improved over the past 11 years, using surveys of appliance manufacturers and home builders and econometrically derived estimates of usage elasticities, cross-price elasticities, own-price elasticities, and other parameters.

This effort has two main purposes of: 1) to derive general lessons for policy analyses that seek to understand the relationships between energy prices, energy use, government policies, and carbon emissions, and 2) to describe the characteristics and limitations of LBL-REM by analyzing the outputs from a large number of different scenarios. In the process of achieving these two goals, the study will also shed light on the potential effectiveness of various policy options for reducing residential-sector carbon emissions.

Comparison of Residential Forecasting Models

F. Johnson, J. Koomey, J.E. McMahon, M.D. Levine , and P. Chan

In the context of the biennial National Energy Strategy (NES), the U.S. Department of Energy has become increasingly interested in the characteristics of end-use forecasting models. This ongoing effort involves a comparison of the LBL Residential Energy Model (LBL-REM) with the Electric Power Research Institute's REEPS II model and with the residential modeling system used for the NES.

The NES documentation reveals information about the number of households, energy prices, projected growth in income, and other primary drivers used for their forecast. The first step of our analysis is to incorporate these data as the primary inputs to LBL-REM and REEPS II and to compare the resulting forecasts with the NES forecast. Outputs of greatest interest in this comparison include total energy consumption by fuel and by end-use and growth rates in these parameters. Anomalies and differences uncovered in this effort will lead to investigation of the structural and methodological differences embedded in these models.

In the first step of this effort, we normalized primary inputs (households, prices, income, etc.) and compared outputs from all three models. In the second phase of the project, we will focus primarily on REEPS II and the NES models, delving further into the algorithmic differences between these two models by running illustrative sensitivity cases. All these results will be documented in a report to appear in FY 1992.

ENERGY CONSERVATION POLICY

Analysis of Federal Appliance Efficiency Standards

J.E. McMahon, B. Atkinson, S. Boghosian, P. Chan, T. Chan, J. Koomey, M. Lecar, M.D. Levine, J. Lutz, G. Rosenquist, O. Sezgen, S. Stoft, I. Turiel, and C. Wodley

The Energy Policy and Conservation Act (P.L. 94-163), as amended by the National Energy Conservation Policy Act (P.L. 95-619) and by the National Appliance Energy Conservation Act of 1987 (P.L. 100-12) and by the National Appliance Energy Conservation Amendments of 1988 (P.L. 100-357), provides energy conservation standards for 12 of 13 types of consumer products* and authorizes the Secretary of Energy to prescribe amended or new energy standards.

Initiated in 1979, LBL's assessment of the standards is designed to evaluate their economic impacts according to the legislated criteria (Figure, see next page).

The economic impact analysis is performed in five major areas:

- *Engineering Analysis*, which establishes the technical feasibility and product attributes including costs of design options to improve appliance efficiency.
- *Consumer Analysis* at two levels: national aggregate impacts and impacts on individuals. The national aggregate impacts include LBL-REM forecasts of appliance sales, efficiencies, energy use, and consumer expenditures. The individual impacts are analyzed by life-cycle cost, payback periods, and cost of conserved energy, which evaluate the savings in operating expenses relative to increases in purchase price.
- *Manufacturer Analysis*, which provides an estimate of manufacturers' response to the proposed standards. Their response is quantified by changes in several measures of financial performance.
- *Utility Analysis* that measures the impacts of the altered energy-consumption patterns on electric utilities.
- *Environmental Effects Analysis* that estimates changes in emissions of carbon dioxide, sulfur oxides, and nitrogen oxides, resulting from reduced energy consumption in the home and at the power plant.
- *Regulatory Impact Analysis* that collects the results of all the above analyses into the net benefits and costs from a national perspective.

*Products covered: 1) refrigerators, refrigerator-freezers, and freezers; 2) room air conditioners; 3) central air conditioners and heat pumps; 4) water heaters; 5) furnaces; 6) dishwashers; 7) clothes washers; 8) clothes dryers; 9) direct heating equipment; 10) kitchen ranges and ovens; 11) pool heaters; 12) television sets; and 13) fluorescent-lamp ballasts.

This year, based on our analysis, DOE mandated updated standards for dishwashers, clothes washers, and clothes dryers. Potential energy savings were demonstrated for these products, and standard levels were identified which are projected to save consumer energy and money without undermining the financial health of the appliance industry. Data collection and analysis continued for nine products: room air conditioners, water heaters, furnaces, clothes washers, direct heating equipment, kitchen ranges and ovens, pool heaters, televisions, and fluorescent light ballasts.

We also continued data collection and modeling to study alternative policies for improving energy efficiency of lighting equipment in buildings, including residential and commercial applications.

In the next year, we will complete the analysis of proposed energy efficiency standards for the nine products listed above. We will begin data collection and analysis for updated standards for refrigerators and freezers, furnaces, central air conditioners and heat pumps. We will also complete the engineering analysis and projections of potential energy savings from more efficient lighting equipment in buildings.

Preliminary results show energy and economic savings for a wide range of policies, including component standards, building codes, incentive programs (rebates and tax credits) and education. The policies differ in magnitude, timing, and certainty of savings, as well as ease of enforcement and administrative burden.

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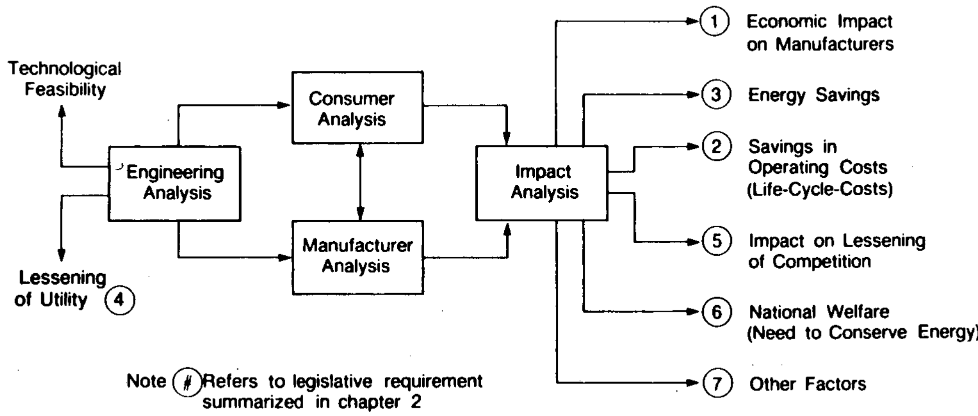

Figure *Analytic framework for the appliance standards analysis. (XBL 856-8918)*

Engineering Analyses of Appliance Efficiency Improvements

I. Turiel, B. Atkinson, S. Boghosian, J. Lutz, and G. Rosenquist

The economic impacts of appliance efficiency standards depend largely on the relation between cost and energy consumption of a consumer product. Our engineering analysis seeks primarily to identify this cost-consumption relationship for selected appliances. Based on earlier analyses, a final rulemaking was published by DOE in May of 1991 for dishwashers, clothes washers, and clothes dryers.

We have completed analyses for eight products: water heaters, pool heaters, direct heating equipment, mobile home heaters, fluorescent ballasts, room air conditioners, ranges/ovens, and televisions. A new initiative for lighting products was completed late in 1991. The advantages and drawbacks of lighting standards and of other lighting energy conservation programs were addressed. Clothes washers were also reanalyzed in 1991, based on additional data for horizontal-axis designs received from manufacturers.

The engineering analysis consists of the following steps: select appliance classes, select baseline units for each class, select design options for each class, determine the maximum technologically feasible design, the efficiency improvement, and the cost for each option for each class. Data are obtained through contacts with trade organizations and manufacturers, from suppliers of purchased parts and materials, and from computer simulations.

In 1992, we plan to begin the engineering analysis of three products: central heating; central air conditioning and heat pumps; and refrigerators and freezers. We will also revise our report on the results of the analysis of existing lighting programs and potential lighting standards approaches.

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Assessing the Impacts of Appliance Standards on Manufacturers

T. Chan and S. Stoft

The Manufacturer Analysis assesses the impact of appliance standards on the profitability and competitiveness of the various appliance-manufacturing industries to be affected by mandatory energy-efficiency standards. The primary tool used by this evaluation is the Manufacturer Impact Model (LBL-MIM). LBL-MIM uses engineering cost and efficiency estimates as well as collected economic and financial data for this analysis. Outputs include price, rate of profit, shipments, revenues, net income, and the standard errors of these estimates. LBL-MIM also provides estimates of retail prices used in the Residential Energy Model (LBL-REM) and in the life-cycle cost analysis.

This year, we collected data and updated LBL-MIM for use in a preliminary analysis of the impact of standards on water heaters, direct heating equipment, room air conditioners, kitchen ranges and ovens, pool heaters, mobile home furnaces, televisions, clothes washers and fluorescent lamp ballasts.

We also made progress in further integrating the demand functions between LBL-MIM and LBL-REM.

We also evaluated the manufacturer impact section of a report to DOE on the feasibility of developing standards for lighting products. Our analysis indicates that standards were not likely to result in any significant adverse impact on the industries involved.

Data collection for the next round of products was also begun. This effort includes a combination of questionnaires to firms; meetings with firms, industry consultants, and trade associations; and plant visits.

In 1992, we expect to complete integration of the LBL-MIM and LBL-REM demand functions, complete and prepare a technical support document for the nine products in the current round of analysis, and reanalyze work done for the nine product rulemaking.

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Analysis of Federal Policy Options for Improving U.S. Lighting Energy Efficiency

B. Atkinson, J. McMahon, P. Chan, T. Chan, J. Eto, J. Koomey, M. Lecar, F. Rubinstein, O. Sezgen, and T. Wenzel

Lighting energy comprises about 35% of electricity consumption in U.S. commercial buildings and more than 10% of residential electricity. This amounts to one quarter of all buildings electricity, or 5.2 Quadrillion Btus (primary energy). The lighting end use provides a major opportunity for achieving savings by implementing energy-efficiency improvements. Considerable interest in lighting has been expressed at both the federal and state regulatory levels. This analysis is expected to form the basis for future Department of Energy policies relating to lighting efficiency.

The study was undertaken to determine the impacts of various lighting efficiency standards, incentives, and information policies. We developed and applied a methodology to quantify savings from potential federal lighting efficiency policies. We studied policies relevant to the following areas: mandatory component performance standards, system performance standards, consumer rebates, dealer rebates, consumer tax credits, voluntary component performance standards, and consumer education programs. The report included engineering analysis of lighting products, consumer analysis, manufacturer analysis, and utility impact analysis.

The analysis considered the commercial and residential sectors. For the commercial sector, the Electric Power Research Institute's COMMEND end-use forecasting model was used. The study bounded national savings estimates between two forecasts, one assuming a baseline with considerable savings and the other assuming modest savings from *existing* utility and government programs and standards. Specific policies studied included standards for fluorescent and incandescent lamps, a combination lamp/ballast standard, fixture standards, prescriptive lighting controls, building codes, and combination lamp/ballast/fixture with controls. The study also analyzed two lamp standards proposed in federal legislation in 1991. For the residential sector, the LBL-Residential Energy Model (LBL-REM) was used to predict savings from component performance standards for lamps.

The study showed significant energy and economic savings from a diverse set of policies. However, the policies differ in the certainty of savings and administrative burden. The figure (see next page) shows a range of the cumulative lighting energy savings by policy for the commercial sector for years 1995 - 2025.

In 1992, we will complete a revision of the lighting analysis based on comments from reviewers of the draft report.

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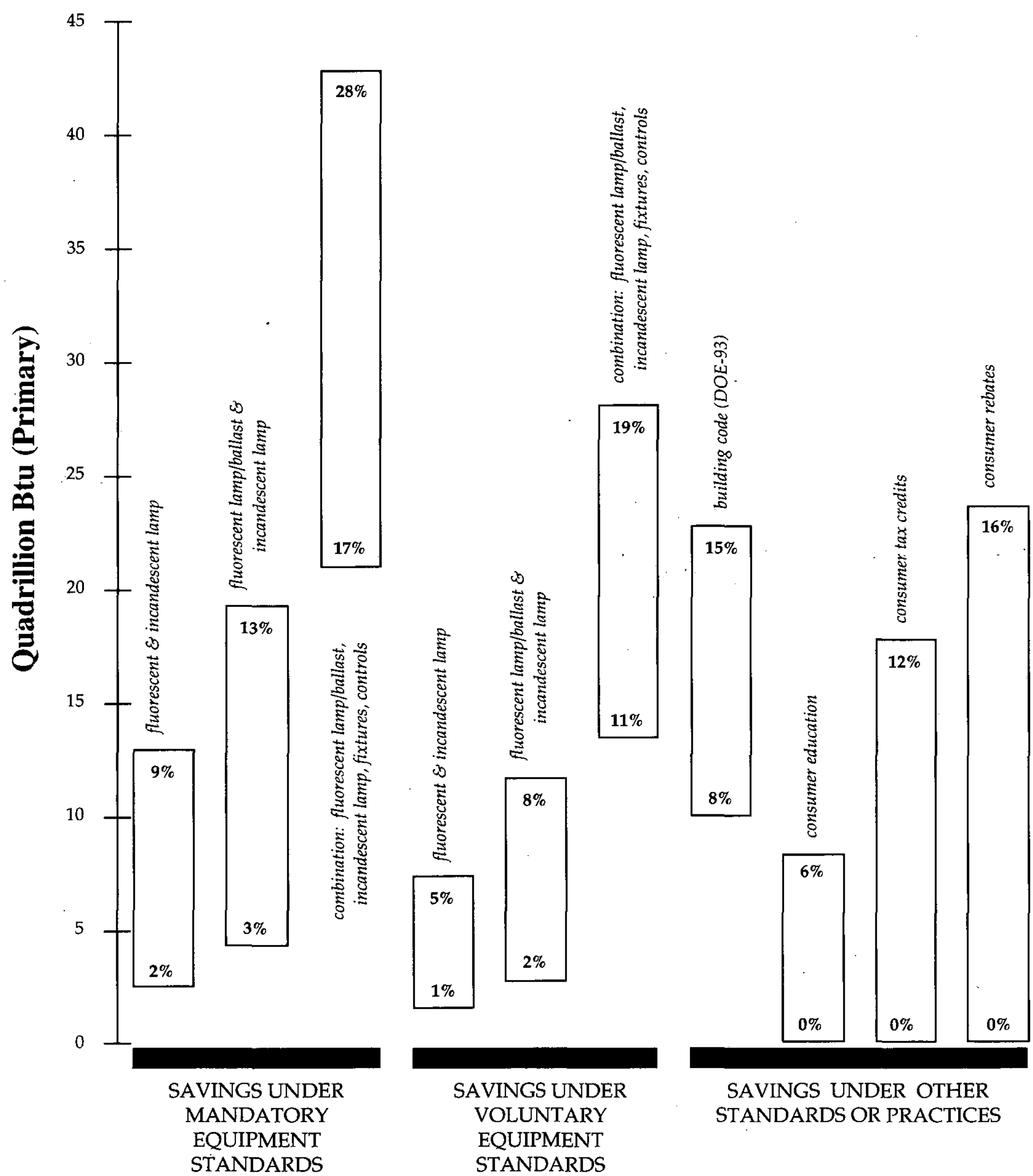

Figure *Cumulative lighting energy savings resulting from major policies for commercial sector, years 1995-2025. Savings range from 0% to 28%.*

UTILITY PLANNING AND POLICY

Integrated Resource Planning: The Role of Competitive Forces

C.A. Goldman, E. Kahn, J. Eto, J. Busch, and F. Krause

As part of our work for the Department of Energy on integrated resource planning, we conducted a study that examined the potential of competitive forces to enhance the efficiency of integrated resource planning and to reduce consumer cost. We examine the efficiency gains resulting from competition in the private power market and ask whether similar forces can succeed on the demand side of the market. We consider the entire market structure–upstream suppliers, distribution intermediaries, and ultimate consumers. The market structure differs substantially between the demand side and the supply side of the electricity market. Demand-side electricity markets have a longer distribution chain and more intermediaries than the supply side, a difference attributable in part to the ultimate retail nature of demand and the wholesale nature of supply, and in part indicates market failures.

We identify four factors that produced cost efficiencies in the competitive market for privately owned electricity generation:

- Standardization of power plant design has enabled some power developers to capture production economies;
- Technical innovations have been introduced by private suppliers. Long-term fixed price contracts create opportunities to increase profits by lowering costs, and these can stimulate developers to innovate;
- Private producers have developed innovative financing strategies which have expanded the scope of capital formation;
- Project developers have formed strategic alliances that link downstream distribution with upstream supply in the private power market.

In all cases, the downstream supplier (i.e., the private developer) improved the efficiency of services (i.e., engineering, equipment, capital, and fuel supply) delivered from upstream suppliers.

We then examine four different ways in which the benefits of competition can be applied to demand-side markets: option 1) innovative approaches to integrate downstream (i.e., utilities) with upstream suppliers of energy-efficiency products; 2) increased competition among energy service providers; 3) competition among the aggregation entities (i.e., utility vs. energy service companies (ESCOs)); and 4) "yardstick" competition among utilities.

The first model involves efforts by utilities to stimulate the market for the next generation of high-efficiency equipment. This effort is currently focused on refrigerators. Compared to conventional utility refrigerator rebate programs, the so-called "golden carrot" incentive mechanism moves much farther upstream in an attempt to change the future efficiency mix of refrigerators produced. The approach reduces transaction costs by working directly with major manufacturers instead of with thousands of appliance dealers/salespersons and with millions of ultimate customers. In addition, the "free rider" problem is minimized by this "market pull" strategy.

A second model involves expanded competition among third-party firms to encompass additional aspects of utility demand-side management (DSM) program delivery. For example, a utility will competitively select firms that can manage and deliver some or all services required by the DSM program for a turnkey fixed price. With this approach, the utility maintains more control over program implementation, compared to DSM bidders and effectively limits the nature and extent of contacts between customers and third-party firms, who utilities perceive as potential competitors.

The third model is explicit or implicit competition between utility DSM programs and ESCOs. Competition between utilities and ESCOs may provide a market test that will serve as a benchmark to assess utility DSM performance. The Wisconsin Public Service Commission's order to Madison Gas & Electric to conduct an Energy Conservation Competition pilot is probably the best example of an *explicit* competition between utilities and ESCOs. Structured competitions between utilities and ESCOs will often require Public Utility Commission (PUC) staff to assume a proactive stance by undertaking direct, sustained involvement in the implementation details of DSM programs. In most DSM bidding programs, competition between utilities and ESCOs is implicit in the sense that the markets and end uses targeted by ESCOs often overlap substantially with existing or proposed utility-sponsored DSM programs.

The final model is "yardstick" competition among utilities in evaluating their DSM efforts. Using this approach, PUCs measure DSM program performance relative to some "yardstick" such as current practice or level of effort of other utilities in the state or region. Commissions set quantitative and qualitative DSM goals and expectations for individual utilities by translating the performance achievements of comparable utilities with the most aggressive programs after adjusting for size differences and unique conditions or circumstances. In practice, the value of–and the ease with which–various "yardstick" indicators can be developed depends on circumstance. While imperfect, the use of "yardstick" competition by regulators to compare utility DSM performance is an area where we expect continued experimentation.

Competitive forces are pervasive and effective on the supply side. On the demand side, decisionmaking is done largely in an administrative fashion and represents the joint consensus of regulators, utilities, and other interested parties. Demand-side resource options are inherently diverse, diffuse, and decentralized, a situation which underlies the myriad market barriers that create these efficiency opportunities. This diversity also leads us to conclude that it is highly unlikely that one type of competitive mechanism, such as bidding, will ultimately emerge as dominant. Instead, a variety of innovative and competitive mechanisms deserving consideration are likely to be promising in terms of improving the functioning of demand-side markets.

The models discussed in this report differ with respect to their underlying vision of the role of the utility in the demand-side arena. Approaches that involve "yardstick" competition among utilities, an emphasis on increased competition among energy service providers for services defined by the utility buyer, and increased utility involvement with upstream suppliers tend to rely more heavily on the utility as the central agent in defining DSM resource opportunities. In contrast, in DSM bidding programs, third-party firms relatively independent of utility control or guidance have a greater role in defining DSM resources and in providing comprehensive energy services.

The state utility regulator is ultimately faced with the responsibility for choosing the emphasis of DSM activities for a particular region. Granting utilities an effective monopoly over DSM may potentially broaden delivery of programs but raises issues of cost control. Competition can provide a check on utility costs but it not always feasible or effective. ESCOs are a limited substitute for utility DSM. Bidding by ESCOs for energy savings will provide some alternative measure of DSM costs, but many incommensurables (such as performance requirements) must be taken into account to make such comparisons. The model of regulation required to deal with the issues raised by integrated resource planning is active because market forces are still weak, particularly on the demand side.

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Independent Power Market: Policy and Analysis

E. Kahn, S. Stoft, and A. Taylor

The independent power industry is becoming a major component of the U.S. electricity supply system. The mixture of a competitive segment with the regulated segment of the utility industry raises a number of analytical and policy questions. During FY91, we examined two aspects of the private power market: 1) the nature of long-term contracts between private producers and utilities; and 2) the role of repowering projects in a competitive wholesale market.

Private power contracts typically involve a generic allocation of risks between developers and utility ratepayers. Developers sign fixed-payment contracts for capacity or investment-related costs. To earn these payments, the projects are subject to performance standards. Developers also agree to a first-year variable cost which is the product of fuel cost and a fixed conversion efficiency, or "heat rate." The heat rate remains fixed, but future fuel costs are adjusted by an external index. Fuel cost indexation effectively transfers most fuel price risk to the utility ratepayer. Almost universally, demand risk is also borne, by the utility and its ratepayers. The primary source of data for this analysis is a sample of actual contracts. The sample includes 20 contracts for 4570 MW from eight states and 13 utilities. Important variations on this generic risk allocation and the most significant additional contract clauses are summarized topically below.

Virtually all contracts have explicit performance standards for generation availability and include penalties for failing to achieve contract targets. Contracts also specify for capacity testing and, frequently, penalties for degradation from contract commitments. Many contracts include "minimum take" restrictions, which limit the utility's operational flexibility. Enforcing performance standards depends on the definition of force majeure. Liberal interpretations can excuse nonperformance.

Fuel price indexation varies. Coal-based projects typically index to GNP or the buyer's costs. Gas-based projects typically use national fuel cost indices or buyer's cost. Projects using imported gas involve indices that will escalate more slowly than domestic gas costs. Only two contracts have explicit benefit-sharing if actual project costs are less than the indexed price. Many contracts allow renegotiation of the base price.

Developers must typically post security deposits that are to be forfeited if the facility never operates. When operational, projects can be terminated for excessive nonperformance. *Force majeure* definitions are key elements of these clauses. Termination penalties are also found in almost half the cases.

Tradeoffs exist between accommodation of developers' needs and the desirability of imposing responsibility. If the prices paid in a lenient contract are low, ratepayers might not be penalized. Similarly, if contract prices are high but terms and conditions are demanding, ratepayers may also be well-served. The present state of the art does not allow a systematic assessment of this kind. Nonetheless, we can observe two trends that suggest that the private power market is functioning reasonably well. First, there is measurable movement to lower prices in this highly competitive market. Second, there is a growing tendency to incorporate increasingly strict terms in the contracts as utilities move away from lenient risk allocation terms that tend to be found in earlier contracts.

Repowering and site recycling are strategies designed to expand electric-generating capacity by using existing depreciated assets. The resource base for these strategies is large. By 1995, over 170,000 MW of fossil-fired capacity will be in excess of 30 years old and approaching the end of its conventional economic lifetime. The residual value of old power plant sites is considerable. This is illustrated by the treatment of site-related issues in the competitive bidding solicitations recently sponsored by utilities seeking new resources. Proposals that are favorably sited in the transmission network derive competitive benefit. Other site-related advantages include access to fuel supply infrastructure, access to cooling water, and environmental permits. Existing power plants, even at the end of their traditional lifetimes, commonly have all these assets.

We explore how these assets might be developed using competitive market forces. While some repowering is being pursued under traditional ratebase regulation, there are four other generic alternatives: 1) utility investment at fixed prices with regulatory preapproval; 2) utility investment under competitive bidding; 3) utility leasing for private producer development; and 4) utility sale of sites for private producer development. The cases involving transfer of site control to independent parties are important for two reasons. First, the magnitude of the retiring plant resource base is so large that it is unlikely to be fully exploitable by the regulated utilities. Second, these utilities show reluctance to invest under traditional ratebase regulation. The existence of a competitive private generation segment could have a beneficial effect on the development of the repowering market.

State regulatory policy will be the critical determinant of whether a market develops for depreciated power plants. Financial incentives will stimulate utilities to redeploy depreciated assets. Without the opportunity to profit from a sale, a utility is likely to hold on to an old power production site. With some benefit in the arrangement for the stockholders, a utility is more likely to entertain the option of selling off an old plant if an independent power producer has introduced an attractive bid for repowering. This means some form of profit sharing between customers and shareholders of the gains from asset sales. These developments are still in an experimental state, however, and no single approach appears to have emerged as a dominant trend.

Future projects will examine the treatment of fuel price risks in competitive bidding for electric-generating capacity and the nature of loan agreements between private power producers and financial institutions.

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Incentives for Utility Demand-Side Management

J. Eto, A. Destribats, and D. Schultz†*

In traditional utility ratemaking, profits are increased by higher energy sales, and lower energy sales decrease profits. This practice is a major institutional barrier to utility acquisition of demand-side resources, which can often provide energy services at lower cost than supply-side resources. The National Association of Regulatory Utility Commissioners now formally recognizes this inherent bias in utility regulation and has begun actively promoting regulatory alternatives to stimulate utility participation in demand-side resource markets. In 1991, working with leading experts from the utility industry, we analyzed the concept of *shared savings,* a particularly promising alternative to traditional ratemaking practice.

The basis for shared-savings incentives is that in order to be cost-effective, utility-acquired demand-side resources must cost less than those avoided on the supply side. As a result, the net benefit provided by avoided supply-side resources less the cost of the demand-side resource can be "shared" between utility ratepayers and shareholders. In this way, shared-savings incentives for utility demand-side management (DSM) activities attempt to harmonize utilities' profit incentive with society's preference for the acquisition of cost-effective demand-side resources.

Shared-savings incentives present a challenge: explicit measurement of energy savings despite the immaturity of such a measurement science. Utilities and commissions must therefore strike a balance between the risks associated with performance of demand-side programs and the rewards provided by shared savings.

We examined this balance and the resulting programs' performance as achieved by three utilities and their commissions. The utilities included Pacific Gas and Electric Company and San Diego Gas and Electric Company (both operating in California) as well as Narragansett Electric Company and Granite State Electric Company (operating in Rhode Island and New Hampshire, respectively). The latter two utilities exist as operating subsidiaries of the New England Electric System.

Although the basic idea behind shared savings is straightforward, program design features and pre-existing regulatory practices complicate comparisons between programs. The most important program design features include: 1) the methods used to determine energy savings, which distinguish between performance of demand-side measures (expressed in savings per participant) and performance of the demand-side program (expressed as numbers of participants); 2) the types of programs eligible for shared-savings incentives; and 3) the existence of supplementary incentives or penalties. Generally speaking, these and other program design features must be viewed in the aggregate

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because they are strongly coupled to one another; leniency in one area is often offset by increased risk in another. The most important regulatory practices include the method of cost recovery for the utility's DSM program expenses and a method for creating utility indifference to sales levels.

The experience of the three utilities in 1991 shows no consensus on how to best allocate the risks and rewards from utility demand-side activities; both utilities and their commissions are gaining experience and are modifying programs. Clearly, however, the incentives have been crucial to the utilities' aggressive pursuit of cost-effective DSM resources—and the incentives have added measurably to society's cost of acquiring these resources.

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Environmental Externality Surcharges in Power System Planning

F.L. Krause, J.F. Busch, and J.G. Koomey

In several states, public utility commissions have adopted surcharges for environmental externalities (adders) to be used in electric utility planning. The Massachusetts adder system applies major surcharges to emissions of sulfur dioxide, nitrogen oxides, and carbon dioxide. In this project we explore the implications in terms of cost and emissions of using the Massachusetts adders as shadow prices to alter the operation (i.e., dispatch) of power plants in the pooled power system in New England. Our analysis has made use of a probabilistic production-cost simulation model to estimate the impacts on the present system and on a resource mix envisioned 15 years hence. The externality cost adders are used to influence the dispatch of a fixed configuration of power plants and are not used to affect the composition of the future resource mix.

Use of externality cost adders reduced emissions of sulfur dioxide and nitrogen oxides 10% to 15% at a production cost penalty of 3% to 4% as compared to conventional dispatch. Precursors of acid rain are reduced mainly by shifting generation away from New England's coal steam power plants.

Carbon dioxide emissions were virtually unaffected by the adders. Although the Massachusetts externality adder system places a high value on carbon emissions, reductions of carbon emissions do not follow. This is because the adders act in aggregate over all pollutants, and specific pollutant reductions are determined by the differences in emissions characteristics of the plants whose generation is lowered or raised.

Least-emissions dispatch reveals the maximum possible emissions reductions available from a fixed resource mix. When present and future power systems are operated on the basis of the Massachusetts externality adder system, emissions reductions are significantly lower than in the least-emissions mode. The adders' impact is even less in the future system primarily because the new resources tend to have lower variable cost than existing ones—so they are already being run at relatively high output levels—and have lower emissions. For environmental externality adders to produce large emissions reductions in plant dispatch, the system must have high-variable-cost/low-emissions resources that the adder can place higher in the dispatch order.

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Review of Utility Experience with Demand-Side Bidding Programs

C.A. Goldman and J.F. Busch

Since 1984, competitive procurement systems have emerged as the dominant approach for acquiring non-utility generation. Demand-side management (DSM) bidding has also been proposed, but experimentation has been more limited. Utilities in Maine, New York, New Jersey, Washington, and Indiana are currently implementing "all-source" bidding processes, which include demand-side resources, often at the request of regulatory commissions. Several utilities in New England have conducted pilot DSM bidding programs or performance contracting programs involving third-party firms. In addition, utilities in Colorado, Oregon, and California as well as the Bonneville Power Administration (BPA) have recently issued solicitations for demand-side resources or are in the design phase, while pilot bidding programs are being considered in Michigan and North Carolina, and for gas utilities in New Jersey.

A defining feature of DSM bidding programs is that they involve customers or third parties (e.g., energy service companies or ESCOs) competing for long-term contracts with utilities which specify amounts of DSM savings to be achieved by a winning participant over a defined time period. However, utilities differ significantly on key program design and implementation issues. These issues include method used to determine appropriate ceiling price, advisability of posting a ceiling price, bid evaluation methods (self-scoring vs. non-self-scoring systems), relative weights to assign to price and non-price factors (e.g., project status/viability), specification of reasonable threshold and eligibility requirements, and linkages between payment terms and verification/monitoring of savings. As utilities gain actual experience with administering DSM bidding programs, interest in program results and performance is increasing as is interest in lessons that can be applied to future programs.

We collected information on potential program costs, the major component of which is incentive payments to winning bidders. Data on other costs included in economic analysis of programs are more speculative. Administrative costs vary significantly during different phases of a bidding program. Additionally, few utilities have systematically collected data on customer contributions to the costs of installed measures (which would be included in the total resource cost test). In some cases, this information was included in ESCO bids; for others, rough estimates of potential customer cost contributions were provided by program managers or ESCOs.

Economic indicators of selected DSM bidding programs are listed in the Table. Our aim was to present program costs on a consistent basis among utilities, using levelized costs per kWh and a common discount rate (11%). Average bid prices and economic lifetimes reported for each program represent a weighted-average based on kWh savings of individual contracts. We typically estimated levelized costs over the term of the contract and believe this approach to be conservative because measure lifetimes usually exceed contract terms. For comparison, we calculated the utility's estimated avoided supply costs at the meter (i.e., accounting for transmission and distribution losses) over a comparable economic lifetime. To provide some guidance on the relative confidence and uncertainties associated with utility payments to ESCOs and customer cost contributions, we have included a confidence level for each utility DSM bidding program (i.e., high, medium, low).

In theory, we would expect that the level of utility payments to DSM bidders would be affected by the following factors:

- the relative mix of DSM options (because of the large variation in life-cycle costs for various measures);
- the degree to which performance risks and marketing and measurement costs are borne exclusively by the ESCOs;
- flexibility in payment streams;
- comprehensiveness of energy services being provided by bidders;
- the relative maturity of the energy services market and perceived competitors (independent power producers and other DSM bidders vs. only DSM bidders);
- information provided to bidders and the method used to set DSM bid ceiling prices (e.g., the utility's avoided supply cost or some lower value).

We would also expect that levelized costs would increase for measures with longer economic lifetimes. In practice, definitive judgments are difficult to make because of the relatively small sample of programs, uneven data quality and lack of consistency, and the presence of confounding factors. With those caveats in mind, we believe certain trends can nevertheless be discerned:

- Utility payments to ESCOs tend to be higher in early performance contracting programs that emphasized installation of all feasible conservation measures whose levelized cost was less than the utility's cost of new generating capacity (BPA's Purchase of Energy Savings), and in solicitations where the DSM ceiling price is set at the utility's avoided supply cost (e.g., New Jersey).
- These initial results also suggest that there is some correlation between the level of utility payments to winning DSM bidders, and the flexibility in contractual terms (particularly payment streams) and the degree of performance risk borne by the ESCO. For example, in its Performance Contracting Program, New England Electric made one-time, up-front payments to ESCOs upon verification of installation; payments were based exclusively on engineering estimates of savings. The company did not post a DSM ceiling price and levelized costs of utility payments to ESCOs ranged between 2.5 to 4.8 cents/kWh, depending upon assumptions related to the load factor and economic lifetime of measures. In contrast, more recent DSM bidding programs (in New Jersey, Maine, and New York) strongly encourage payments over time which are linked to the ESCO demonstrating that savings have actually occurred. This increased performance risk, as well as associated monitoring costs (which are often part of the ESCO's bid), appear to be reflected in higher bid prices.
- Some evidence suggests that prices of winning bidders are decreasing over time, despite many confounding factors (e.g., mix of DSM measures, varying DSM ceiling prices, etc.). For example, payments to ESCOs are significantly lower in recent bidding programs compared to early performance contracting programs. Central Maine Power (CMP), which has the most experience with DSM bidding in its Power

Partners Program, reports that winning bid prices are lower in their second request for proposal (RFP) as compared to the first RFP (4.8 vs. 3.4 cents/kWh). In contrast to its initial RFP, CMP did not provide information on its ceiling price in RFP #2, as bidders' price offers were compared against each other.

• We believe that it is inappropriate to compare the costs of DSM bidding programs with most conventional utility-sponsored DSM programs, given that winning bidders typically bear substantially greater performance risks. We will be in a better position to assess the relative value and cost of DSM bidding programs as resource options as ESCOs produce and are paid for verified, metered savings and as long-term impact evaluations become a routine component of other utility-sponsored programs.

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Table *Economics of DSM Bidding Programs*

Utility	Utility Payment (¢/kWh)	Customer Payment (¢/kWh)	Avoided Supply Cost (¢/kWh)	DSM Ceiling Price (¢/kWh)	Economic Lifetime (yrs.)	Confidence Level
Performance Contracting						
BPA	6.8	NA	NA		7-18	High
Boston Edison	5.3	NA	7.8		10	High
New England Electric	2.5-4.8	NA	4.5-4.9*		3-7	Low
DSM Bidding						
CMP #1	4.8	0.6	6.7		12	High
Orange & Rockland (NJ)	6.5	NA	7.6		15	High
Jersey Central Power & Light	5.7	1.6	7.2		13	High
Public Service Electricity & Gas	6.0-6.7	NA	7.1		NA	Low
CMP #2	3.4	0.5	6.6*		15	Medium
Puget Power	2.7-4.7	NA	5.8-6.6	4.6-5.4	10	Low

GLOBAL ENERGY/ENVIRONMENTAL ISSUES

Electricity End-Use Efficiency: Experience with Technologies, Markets, and Policies Worldwide

M.D. Levine, H. Geller, J. Koomey, S. Nadel,* and L. Price*

Electricity generation produces more than 30% of energy-related carbon dioxide emissions to the atmosphere. During the past 20 years, half of all increases in energy-related carbon dioxide emissions were from electricity. There is strong reason to believe that the factors that have led in the past to electricity increasing its share of total energy demand will continue. A large fraction of growth in electricity generation will take place in the developing world.

Our project has assessed the opportunities for electricity end-use efficiency on a global basis as an important mechanism for reducing growth of greenhouse gas emissions. We prepared a report for the U.S. Department of Energy for submission to the Intergovernmental Panel on Climate Change (IPCC). The report will be reviewed by the IPCC for submission to the United Nations Conference on Environment and Development, to be held in Brazil in June, 1992. The report covers these topics:

- Status of available technologies for increasing electricity end-use efficiency,
- Review of factors currently limiting application of end-use efficiency technologies, and
- Review of policies available to increase electricity end-use efficiency.

Basic conclusions reached in the report:

- Half of the increases in energy-related carbon dioxide emissions in the last two decades came from electricity production, which is likely to account for a comparable share in the future.
- Increases in electricity end-use efficiency beyond those expected to occur under current policies can cut the growth of electricity use and associated carbon emissions significantly. An example of a preliminary estimate of the technical potential for electricity end-use efficiency improvements for India is shown in the Figure.
- There has been sufficient experience with both technologies and policies to have confidence that significant increases in electricity end-use efficiency are possible in practice.
- Many end-use efficiency investments are more cost-effective than new electricity supply investments when evaluated using common criteria (e.g., using the same discount rate).
- Policies such as utility demand-side management programs, information and labeling programs, voluntary and mandatory appliance and building standards, and "golden carrot" financial incentives have been successful in accelerating investments in end-use efficiency. Policies that remove market distortions serve to promote both economic and end-use efficiency. Policies that try to compensate indirectly for market distortions can sometimes promote economically inefficient investments as well as economically efficient ones.

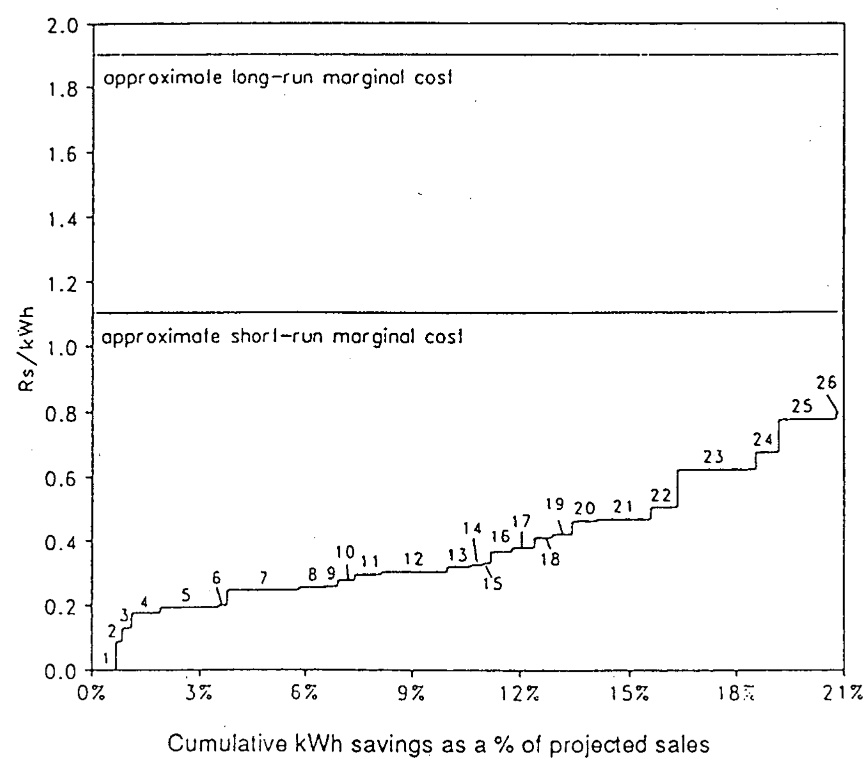

Figure *Supply curve for conserved electricity in India.*

*American Council for an Energy-Efficient Economy

• Making these efficient electricity end-use technologies widely available in developing countries could contribute in important ways to a global effort to increase electricity end-use efficiency, thus reducing growth in electricity supply and in greenhouse gas emissions.

Continuing work on the project is expected to evaluate costs and benefits of specific technology responses to increase electricity end-use efficiency.

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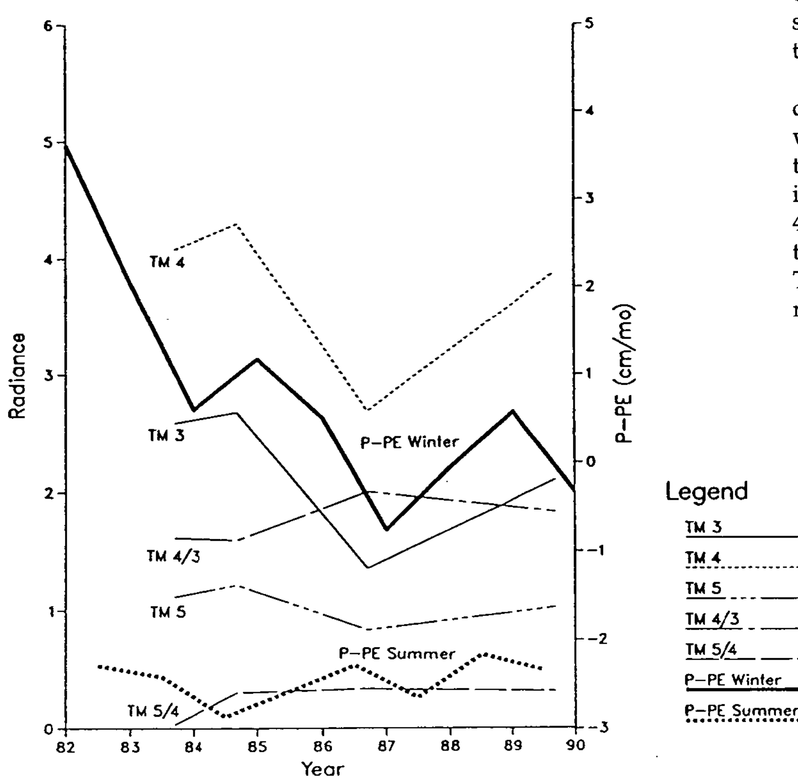
Remote Monitoring of Effects of Climatic Change on Vegetation

R. L. Ritschard and M. F. Landsfeld

Canopies of natural vegetation can respond to climatic variation by exhibiting a range of changes in leaf anatomy, biochemistry, morphology, and canopy structures. Each of these changes will alter the reflectance of radiation from canopies in broadly predictable ways, making optical remote sensing a potentially powerful tool for tracking changes in vegetative conditions due to climatic influence. Our study attempts to determine the feasibility of using satellite data to monitor interannual changes in vegetation canopy conditions based on changes in climate (i.e., temperature and precipitation).

For the study, we selected three vegetation types—northern coastal scrub, coastal sage scrub, and grassland—in the San Bruno Mountain State and County Park (south of San Francisco). Fourteen sites were used to estimate foliar cover of dominant species of plants and percent of exposed ground.



In addition, daily weather data were obtained and used to compute the various climatic variables. Potential evapotranspiration was computed from temperature, relative humidity, and latitude data. Monthly water surplus or deficit values were computed as the difference between monthly total precipitation and total potential evapotranspiration. These vegetation types and climate data were then compared to satellite images from four cloud-free time periods at the end of the summer dry season (September 1983, 1984, 1986, and 1989).

Because its spatial resolution (30m) allows one to distinguish distinct vegetation types, LANDSAT Thematic Mapper (TM) satellite data were used for this study. Previous laboratory studies have elucidated the relationship between reflectance from drought-stressed leaves and TM spectral bands. TM Band 3 (red region, 630 nm), which can be used to identify leaf chlorophyll content, increases as chlorophyll breaks down because of drought-related conditions. TM Band 4 (near infrared region, 760–900 nm) is sensitive to leaf water content and its radiance increases as leaves dry out. TM Band 5 (middle infrared region, 1550–1750 nm) increases as fall leaf moisture decreases. After registering LANDSAT TM scenes to topographic maps of the study area, the satellite data (which are atmospherically corrected) are overlain the study sites using ERDAS software and a geographic information system.

Results (Figure) show that as the drought continued during the late 1980s—indicated by winter and summer water deficits, i.e., precipitation (P) minus potential evapotranspiration (PE)—spectral reflectance of TM Band 3 and 4 in coastal sage scrub show steep increases. The ratio of Bands 4/3 also responds but at a lesser rate. Near infrared reflectance (TM4) would be expected to rise as foliage dried out. The ratio of Bands 5/4 is less sensitive to variations in moisture and the reflectance of Band 5 shows little reflec-

Figure *Satellite and climatic data for coastal sage scrub, San Bruno Mountain State and County Park, California.*

tance. The absolute lower reflectance in the middle infrared (TM Band 5) means that absolute changes as a result of leaf drying will be less. Field results are consistent with this reduced sensitivity in Band 5. The present results along with those reported last year demonstrate that Mediterranean-climate chaparral species such as the northern coastal shrub show canopy changes that are sensitive enough to variations in precipitation conditions to affect spectral reflectance patterns of LANDSAT TM data. Thus, monitoring of the vegetative response to climate change may become possible using satellite-based sensors.

Energy Efficiency and Air Quality in the Los Angeles Basin

R. Ritschard, H. Akbari, M. Landsfeld, D. Sailor, and H. Taha

The relationship of end-use energy efficiency and pollutant emissions is not now being adequately addressed in most local air quality management districts. The major reasons for this deficiency are that policymakers and regulators do not always have enough information about this relationship nor have access to adequate methods for incorporating these factors into their planning and regulatory processes. A multiyear project was recently initiated as part of the California Institute for Energy Efficiency's Air Quality Impacts of Energy Efficiency Program. This study addresses two broad objectives. First, existing emissions calculation procedures will be evaluated and improved so that energy efficiency considerations can be incorporated into them and estimates of possible reductions of fuel combustion emissions can be made for the buildings' sector. The second objective is to evaluate novel, indirect approaches for reducing or delaying the production of photochemical smog including possible temperature reductions resulting from variations in surface characteristics within the Los Angeles Basin due to tree planting and changes in albedo (i.e., surface reflectance).

During the first year, the work is organized into three interrelated project elements conducted by an interdisciplinary research team from LBL, UCLA, and Systems Applications International. The project elements (Figure) include

• emissions studies to develop data for fuel combustion sources and for trees that can directly affect the production of photochemical smog;

• studies of surface characters in the Basin that include quantitative data on vegetative cover, surface roughness, albedo, surface moisture, and soil characteristics;

• meteorological modeling studies to assess the effects of surface modifications on temperature, wind profiles, and other meteorological conditions.

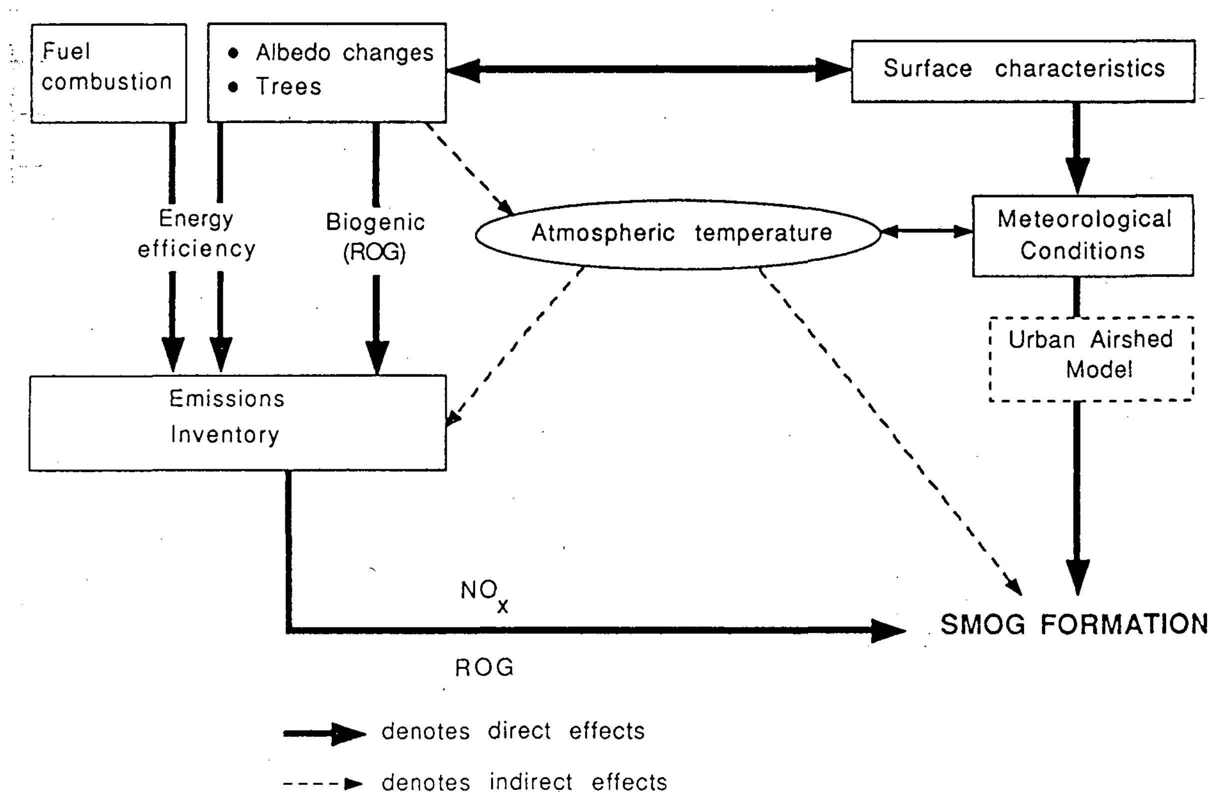


Figure *Direct and indirect ways to improve air quality in the Los Angeles Basin.*

Photochemical smog production will be studied in future years using the emissions profiles and "new" meteorological conditions that result from the surface modifications as inputs to an air pollution model (urban airshed model).

The emissions studies will provide estimates of end-use emissions from the building sector and biogenic emissions of reactive organic gases (ROG) from trees, which can directly serve as precursors to the production of photochemical smog. The emissions studies will also develop improved calculational procedures for projecting emissions and a better understanding of the effects of temperature on both end-use emissions and biogenic emissions from trees.

The characterization of the surface conditions resulting from tree-planting programs and changes in albedo are needed to develop credible data that can be used as inputs to both the meteorological and air pollution models. Surface conditions resulting from massive tree-planting programs and changes in the surface albedo will be compared to existing meteorological profiles for the Basin to determine how these factors affect key meteorological variables. In next year's effort, these meteorological conditions will serve as inputs to the air pollution model so that the effects of surface modifications on photochemical smog formation can be quantified. Using this approach, we expect to demonstrate the causality between urban temperature reductions (through tree planting and increased surface albedo) and decreases or delays of photochemical smog episodes.

The Role and Impact of Energy Efficiency in Developing Countries and Eastern Europe

M.D. Levine, A. Gadgil, S. Meyers, J. Sathaye, J. Stafurick, and T. Wilbanks†*

The objective of this project has been to explore efficiency improvements as an energy strategy for developing countries and Eastern Europe. The final report has been distributed widely to technical and public policy audiences to promote the creation of significant new energy efficiency programs in these countries, with assistance from the United States and other modern industrialized nations. The report describes the evolving energy patterns in developing countries and outlines the role that energy efficiency can play in the near- and mid-range future. It summarizes the main issues that must be confronted in improving energy efficiency, together with the growing record of success in this regard. Finally, it suggests what needs to be done to accelerate energy efficiency improvement in the developing world and Eastern Europe, as a fundamental contribution to economic and social development.

Some key observations have resulted from the research:

- Most of the developing world currently faces a growing need for energy services in order to support economic and social development, but these countries possess inadequate resources to meet that need.
- On a per capita basis, developing countries in 1987 consumed an average of 18 million Btu in commercial fuels and an additional 8 million Btu in biofuels, compared with more than 130 million Btu in Western Europe and 305 million Btu in the United States.

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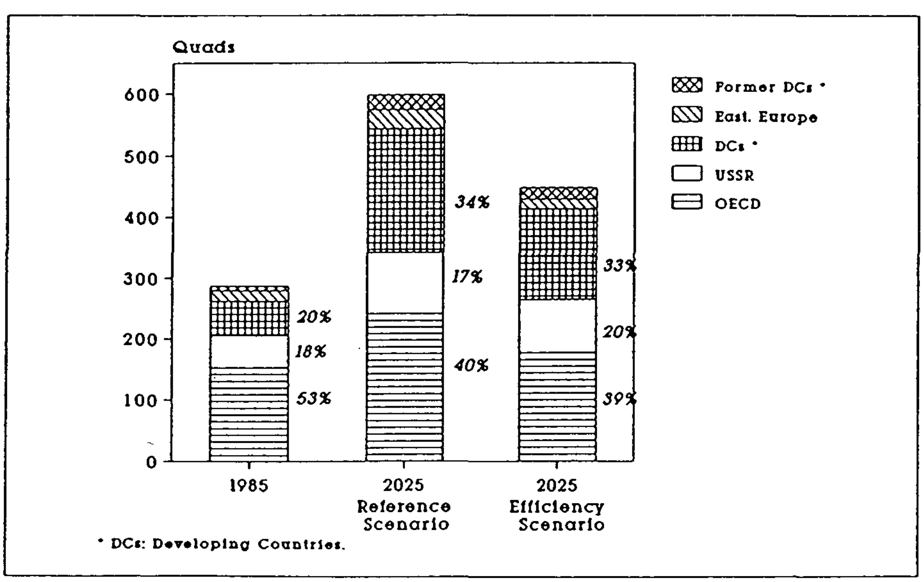

Figure *World primary energy consumption, shown by regions.*

• Although per capita commercial energy consumption in the developing world remains less than 15% of that of the developed world, the rate of growth in energy consumption has been far higher in the developing countries for the last two decades.

• Commercial energy consumption in the developing world grew around 20% faster than gross domestic product (GDP) between 1973 and 1987. The relationship between energy consumption and GDP has varied between regions and over time.

• Generally, developing countries and Eastern Europe require substantially greater quantities of energy resources to deliver one unit of useful energy than do modern industrialized countries.

The project analyzed energy scenarios for developing and industrialized countries for the year 2025 (Figure). The reference case shows global energy consumption doubling from 300 to 600 Quads between 1990 and 2025. An efficiency scenario, relying on the aggressive promotion of cost-effective energy conservation in all nations, reduces growth to 450 Quads by 2025.

In the reference case, energy demand in the developing world increases by a factor of four by the year 2025; energy demand doubles in the efficiency case. (Energy demand increases only about 15% for the industrialized nations in the efficiency case.) This reduction, which in the efficiency case is presumed to occur without loss of energy services, produces an energy future that relieves enormous stresses on the environment and on capital markets.

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Energy Conservation Investments in China

*M.D. Levine and L. Xueyi**

Until 1978, energy production and use in China grew very rapidly, during most years at a rate of one and one-half to two times that of the economy. This is not surprising, considering the emphasis placed in China on the development of heavy industry, the lack of adequate price signals and other mechanisms to balance energy supply and demand, and the general inattention given to efficient resource allocation by leading Chinese planners.

The considerable reductions in energy growth since 1978 are surprising when compared to the experiences of other developing countries. During the last decade, energy demand in China has grown only 50% as rapidly as an admittedly overheated economy. Growth of energy demand substantially below economic growth is unusual in the developing world.

This project explores the factors that have motivated energy planners in China to pay more attention to energy conservation. It summarizes information never before made available outside of China about types of programs undertaken, the criteria used to evaluate energy efficiency investments, and the performance of these investments. It focuses on the period 1981 to 1985 when the Sixth Five-Year Plan was implemented. This period is of great interest because it represents a radical shift in energy policy in China. A massive and ambitious plan for investing in energy savings programs was initiated along with other measures by which the government supported energy conservation.

The most important finding of the study is that the Chinese have made very large investments in energy efficiency: 8 billion yuan (or more than $3 billion) from 1981 to 1985. This investment was highly cost-effective. We estimate that it reduced energy growth by more than 25 million annual tons of coal equivalent, thereby reducing annual growth from 7% to 4% by 1985. This result is significant and important. The conservation supply curve, applied only to those programs carried out during the Sixth Five-Year Plan, illustrates the impacts of these programs (Figure).

Continuing work explores the policies and programs that have been implemented in China to complement the conservation investments. In the future, we plan to assess the performance of energy conservation investments during the Seventh Five-Year Plan.

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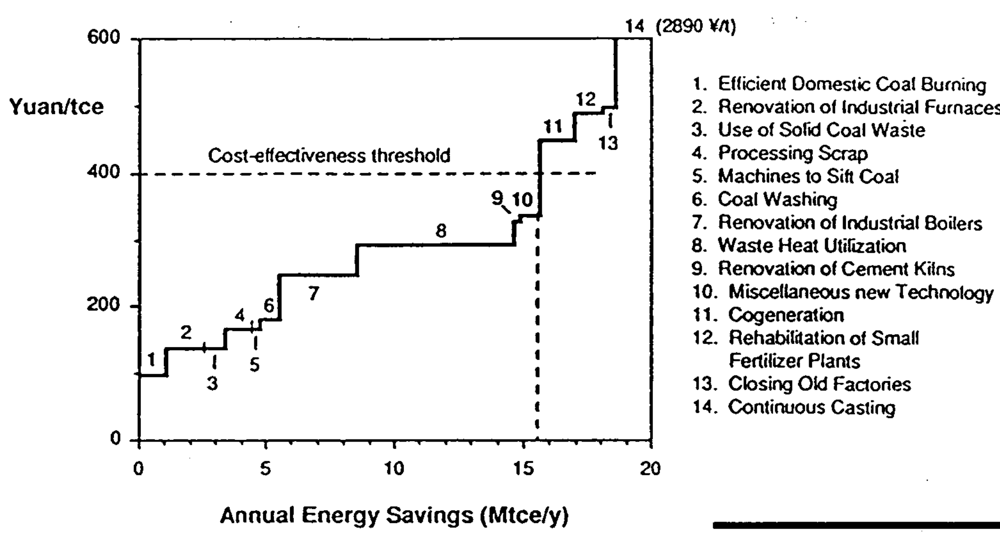

Figure *Cost of conserved energy in China's Sixth Five-Year Plan. (Mtce = one million tons coal equivalent)*

An Overview of China's Energy System

M.D. Levine, S. Lang, W.B. Davis, R.J. Hwang, F. Liu, and J. Sinton

The objective of this project has been to study energy issues in the People's Republic of China related to global climate change. The rapid historical growth of energy in China, combined with the high proportion of coal use in the energy economy and the immense population of China, has made China a major contributor to global release of greenhouse gases.

This project involves close collaboration with Chinese researchers, particularly at the Energy Research Institute of the State Planning Commission. Work has concentrated on four topics:

- compilation of statistical data describing the evolution of the Chinese energy system;
- review and analysis of energy conservation programs in China;
- analysis of factors contributing to overall reductions in energy intensity in China over the past decade; and
- energy use and conservation opportunities in buildings.

Some key findings of the research to date:

- Extremely rapid economic growth in China has led to rapid increase in energy consumption.
- Despite the rapid growth in energy supply, China has persistent shortages of energy, particularly electricity and, more recently, coal.
- China has devoted considerable effort to improving the efficiency of energy use; as a result, energy has grown only half as rapidly as gross domestic product (GDP) over the past decade (Figure).
- Nevertheless, energy use remains very inefficient in China. However, care must be taken in making comparisons between China and industrialized countries. In the steel industry, for example, raw data suggest that the energy required to produce a ton of steel in China is twice that required in the U.S. A more careful analysis, in which corrections are made for accounting differences, differing products, and the like, reveals that the average intensity of Chinese steel plants is about 40% greater that U.S. plants.

Continuing work includes research in all four areas of the project and publication of a monograph on critical energy issues facing China. Future work will involve assembling a conservation supply curve for China and developing scenarios of energy supply and demand for China for the year 2025.

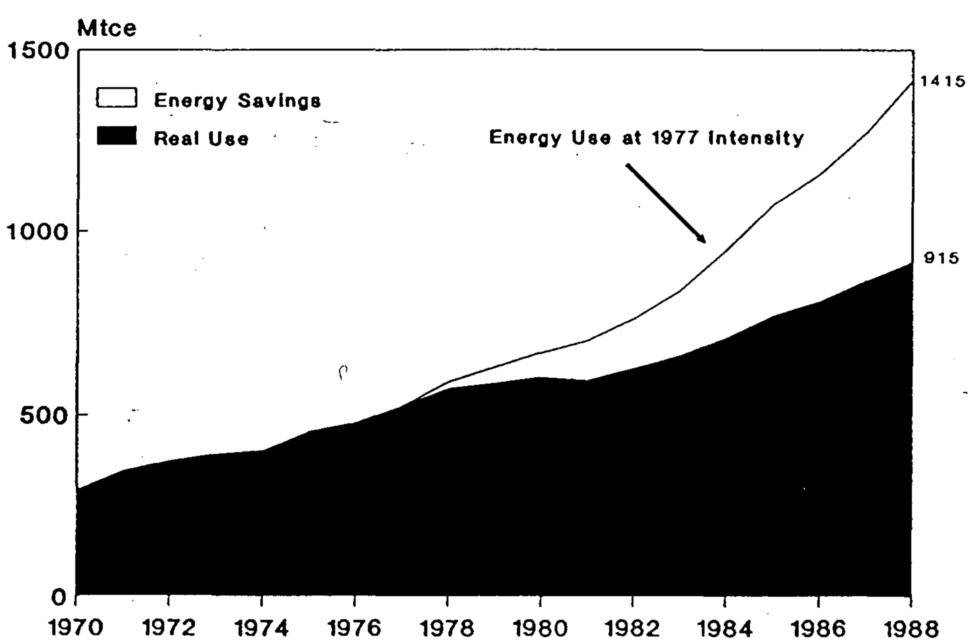

Figure *Energy/GDP growth in China. Here GDP is national income and is at 1980 constant prices. (Mtce = one million tons coal equivalent)*

INTERNATIONAL ENERGY STUDIES

Energy Efficiency and Human Activity: Past Trends, Future Prospects

L. Schipper and S. Meyers, R. Howarth, and R. Steiner

The result of this project is a book that presents an analysis of historic trends in global energy use, describes future prospects, and discusses policies for restraining growth in energy use. The book draws on analyses of energy use conducted by the International Energy Studies Group over the past decade. We apply an analytical framework that considers three basic factors that drive energy use in each sector: activity, structure, and energy intensities. We give separate coverage to the industrial countries, the developing countries, and the Former East Bloc.

The major part of the book describes how and why energy use has changed in the world since 1973. Energy intensities in manufacturing have declined continuously in the Organization for Economic Cooperation and Development (OECD) countries, contributing to a fall in energy use despite considerable growth in activity. In passenger travel and freight transport, shifts toward more energy-intensive modes such as automobiles, air travel, and trucks have pushed energy use upward. In the residential sector, structural change, especially increase in appliance ownership, has caused energy use to grow in much of the world. In the service sector, fuel intensity for heating has declined greatly in the OECD countries, but electricity intensity has risen. In summarizing the past experience, we discuss several issues: What was the role of higher energy prices? Of energy-efficiency policies? Did energy savings represent breaks in long-term trends?

In considering the future, we used the historical analysis as a guide, supplementing it with judgments about the possible evolution of key trends. Growth in activity will be especially strong in the developing countries, and structural change is likely to increase energy use considerably as well. The greatest potential for structural change is in the Former East Bloc, but the pace of change is very uncertain. Structural change is occurring much more slowly in the OECD countries. In considering future energy intensities in each sector, we discuss the direction in which trends seem to be pointing and the potential for reducing energy intensities. There is considerable potential for lowering intensities in all sectors and country groups, but the direction of current trends makes it unlikely that most of the potential will be realized without greater action than is now occurring. We illustrate the extent to which energy intensities might be reduced by presenting scenarios for the OECD countries and the Soviet Union. With higher energy prices (resulting in part from internalization of environmental externalities) and strong energy-efficiency policies, intensities in the OECD countries in the year 2010 could be nearly 50% less on average than the level to which trends seem to be pointing (Figure). The Soviet scenarios suggest that intensities could decline by almost that much if economic reform is successful and technology levels are upgraded to Western standards. In both cases, however, achieving reductions of this magnitude will take considerable policy effort.

The last part of the book presents an overview of policies and programs that can help to change the course of energy use. These include reform of energy pricing, efficiency standards, financial incentives, and innovative methods. In conclusion, we summarize the reasons why restraint in energy use is an important strategy for reducing environmental problems and supporting sustainable development worldwide and outline key steps for achieving such restraint. We call for strong action by governments at all levels, but stress the importance of considering the full range of factors that will shape realization of the energy-efficiency potential around the world and the need to look beyond energy policy for solutions. We suggest how the emergence of a global market economy with relatively open borders could enhance efforts to improve energy efficiency and contend that strong policies in the OECD countries to encourage greater energy efficiency would have profound effects worldwide.

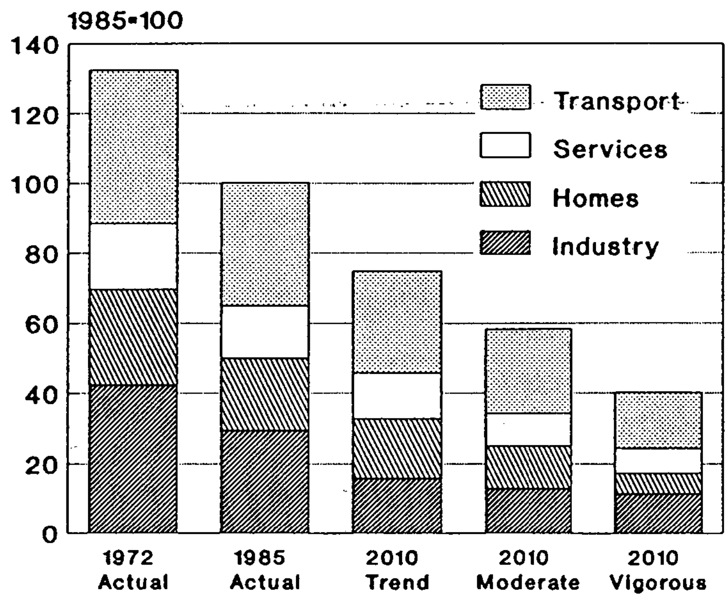

Figure *Effect of reductions in energy intensities on OECD final energy demand: past experience and scenarios for the year 2010. Activity and sectoral structure are held constant at 1985 levels; the scenarios illustrate the intensity effect only. The Trend scenario indicates how energy use might evolve without strong policies. The Moderate and Vigorous scenarios indicate the potential impact of efficiency policies and higher energy prices.*

Improving Appliance Efficiency in Southeast Asian Nations: The Upstream Strategy

L. Schipper, A. Meier, and S. Meyers

We studied the pattern of household electricity use in urban Java, Indonesia, based on results from a 1988 World Bank survey of 2700 households, as well as the market for and characteristics of appliances currently sold in Indonesia. We estimated the degree of cost-effective improvement in appliance energy efficiency that could be achieved. We estimated the impact on future electricity demand given two scenarios of penetration of higher efficiency. We also studied the barriers to improvement of appliance efficiency and described various policy approaches that the government could take in order to accelerate the adoption of higher efficiency appliances. We then analyzed the house electricity use patterns of the other major nations of South East Asia (the Philippines, Thailand, and Malaysia) and found that similar savings are attractive in these countries as well. We conclude that concerted efforts to improve the efficiency of new appliances in this region could reduce future household electricity demand by at least 30% over a reasonable base line.

After reviewing a variety of programs that might achieve these savings, we proposed the "Upstream Strategy," which involves incentives to manufacturers to produce efficient appliances. This will accelerate improvements in efficiency of appliances and reduce the need for expansion of the power system. Part of this strategy is providing financing to appliance manufacturers so that they will improve their products without raising prices significantly. Testing and labeling are also key parts of this strategy, as is marginal cost pricing of electricity.

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Fuel Economy, Fuel Use, and User Costs for Car Travel: Preliminary Findings from an International Comparison

L. Schipper, K. Dolan, and R. Steiner

This project studies how policies in Europe and Japan have shaped modal and vehicle use and resulting fuel consumption and emissions. Understanding the factors influencing fuel use and fuel economy in future automobiles is important if concerns over both local emissions of pollutants (e.g., NO_x, CO, and CO_2) require restraint in future automobile fuel use. Among the factors we have examined are 1) fiscal policies such as fuel and vehicle taxation, parking fees, and company-car privileges; 2) income; 3) land use; 4) personal travel patterns; 5) transit policies; and 6) technologies. These factors were evaluated in relation to fuel consumption and driving behavioral patterns in the United States. Europe's and Japan's lower per capita automobile fuel use, compared to that of the Unites States, suggests that policy measures in these countries may have contributed significantly in their efforts to restrain automobile fuel use. Nine countries were studied: Denmark, France, Germany, Italy, Japan, Netherlands, Norway, Sweden, and the United Kingdom.

Although our more formal statistical review is still underway, several conclusions are evident:

• Fuel prices have a significant effect on per capita automobile fuel use and affect fuel intensity of automobiles as well.

• Most of the countries we studied realized lower real fuel prices in 1988 than in 1970 and actual automobile fuel economy did not change significantly in many of these countries.

• Fuel economy improved far more in the United States than in any other country between 1973 and 1988. Indeed, during this period Americans saw the greatest decline in the cost of driving a distance of one kilometer. This suggests that the U.S. Corporate Average Fuel Economy (CAFE) standards had an important effect on fuel economy there.

• Growth in automobile ownership and use in Europe over the same time period, in part at the expense of mass transit, was only temporarily interrupted by brief periods of high fuel prices. Although a permanent gap appears to exist between per capita auto fuel use in the United States and that in Europe, the actual difference has declined significantly because of the increase in auto ownership in Europe.

• Higher incomes in Europe, boosted by company-car privileges in some countries, encouraged the acquisition of more powerful and larger automobiles.

• Despite automobile and fuel prices, other policies within each country tend to favor driving. The exceptions are countries where no automobiles are manufactured.

• Finally, fiscal incentives are effective in motivating consumers to purchase "cleaner" automobiles.

In conclusion, the present low real prices of fuel (i.e., at the end of 1991) encourage growth in travel and related fuel use, the acquisition of more and more powerful automobiles, and their resulting emissions. If reducing both automobile fuel use and emissions is an important goal, countries must accept strategies that both raise the cost of fuel-intensive vehicles and raise the marginal cost of driving a distance of one kilometer.

Energy Use in Denmark in a Long-Term Perspective

L. Schipper, R. Howarth, and B. Andersson

The International Energy Studies Group was asked by the Danish Energy Agency to analyze developments in energy use in that country since the 1970s (and from earlier times where possible), to evaluate Denmark's achievements in saving energy, and to compare those achievements with developments in other industrialized countries. In our work, we found that Denmark achieved significant energy savings since 1972. In fact, virtually no country in Europe achieved a larger reduction in its energy use through increased energy efficiency than Denmark.

The study was initiated by thoroughly analyzing the structure of Danish energy use—characteristics of housing and household equipment, the structure of transportation activity, the production mix in industry—as well as the use of energy associated with each of these features in the Danish economy and Danish life. From these data, we developed time series of energy intensities, energy use per unit of activity or output for manufacturing industries, space heating, electric appliances, travel and freight activity, and other energy uses.

From this analysis, we found many surprising characteristics of Danish energy use. Danes have one of the highest indoor living standards in Europe, but among the fewest automobiles. They travel approximately average distances for people in Northern Europe, with a rather high use of buses and railroads. Their industrial mix is less weighted towards raw materials than those of most of their neighbors. In all, changes in the mix of activities in Denmark led to increases in energy use, but at a lower rate that the overall increase in the Gross Domestic Product (GDP).

Danish energy use is very efficient today, having improved markedly since the early 1970s. Danish space heating has one of the lowest intensities of all Organization for Economic Cooperation and Development (OECD) countries; the improvements since 1972 in space heating were the largest of any country we have studied. The same can be said for the stock of household appliances. Danish automobiles have (with Italy) the lowest fuel intensity of the major OECD countries, having declined by nearly 20% since 1972. These changes contributed to important energy savings in Denmark. On the other hand, we observed a marked decline in the efficiency of freight hauling by truck, as well as an increase in the share of trucks in the overall mix of domestic freight in Denmark. And the load factors in Danish cars fell significantly. These changes, which are consistent with a trend observed in most other OECD countries, erased much of the energy savings that otherwise would have appeared in the transportation sector.

Using a methodology we have developed, we quantified the overall changes in the structure of energy use and changes in energy intensities. Changes in the levels and structure of activities, which together define the level of energy services provided to Danes and their economy, alone caused an increase in final energy use of 26% between 1972 and 1988, or 27% if losses in district heat and power production are counted. By contrast, the GDP in Denmark increased 44%. Thus, changes in the underlying structure of the Danish economy alone reduced the ratio of energy use to GDP. More important, declining energy intensities in the household, service, and industrial sectors led to reductions of 29% in final energy use and 19% in primary energy use. Put another way, the Danish economy would have required 28% more primary energy than it actually did in 1988 had not energy efficiencies improved since 1972.

In the coming year, we will prepare scenarios of future energy use in Denmark and develop a comparison of energy use in Denmark, Norway, and Sweden, with particular emphasis on the changing lifestyles of the Scandinavian people.

The Economics of Sustainability

R.B. Howarth and R.B. Norgaard

The principle of sustainable development—that natural resources should be managed to meet current needs as fully as possible while ensuring that the life opportunities of future generations are undiminished relative to the present—has won broad acceptance among policymakers and the public at large. Sustainability implies a concern for the long-range future that is not captured in the conventional cost-benefit criteria of economic analysis because cost-benefit analysis discounts future costs and benefits in a manner that attaches essentially no weight to events that occur a generation or more in the future.

In this project we explore the relationship between cost-benefit analysis and the sustainability criterion in the conceptual realm of economic theory. While the point is often overlooked by policymakers and even economists themselves, cost-benefit analysis is concerned with the efficient allocation of resources such that it is impossible to improve the welfare of one individual or group with out rendering another worse off. Cost-benefit techniques cannot be used to identify a "social optimum," which requires not only economic efficiency but a just distribution of wealth between members of society as judged by prevailing social values. Efficiency and equity are interdependent because the distribution of wealth determines the relative prices and other economic variables that go into a cost-benefit study.

The relevance of this framework to the sustainability principle is as follows: An economic future will be sustainable only if sufficient assets, including environmental quality, natural resources stocks, and physical capital, are preserved for the use of future generations. The "optimal" division of assets between generations can only be addressed if the concept of "optimality" is defined in accordance with moral principles. In this respect, the sustainability rule is emerging as an ethical construct to define principles of fairness between generations.

Once issues of sustainability have been adequately addressed, then cost-benefit techniques can be used to improve economic efficiency to the benefit of both present and future societies. Thus, cost-benefit analysis and the sustainability criterion are seen to be complementary rather than competing modes of policy analysis.

In ongoing research, we are exploring the implications of this synthesis for global climate stabilization policy. Although the cost-benefit approach suggests that at least modest reductions in greenhouse gas emissions are warranted (based on their perceived social costs) the economic impacts of climate change are very difficult to anticipate. Although the net future impacts of climate change could be small, the scientific literature suggests the possibility that irreversible and catastrophic impacts on future generations cannot be ruled out. Since the sustainability approach can be interpreted as requiring moderate sacrifices on the part of present society to reduce catastrophic future risks, the approach offers a rational basis for aggressive policy action.

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Manufacturing Energy Use in Eight OECD Countries: Trends Through 1988

R.B. Howarth and L. Schipper

This project reviews the evolution of manufacturing energy use in eight industrialized nations: the United States, Japan, the Federal Republic of Germany, France, the United Kingdom, Denmark, Sweden, and Norway. The results indicate that sectoral energy use fell in these nations from 28.7 EJ in 1973 to 24.0 EJ in 1988. Oil use fell from 8.7 to 3.7 EJ over the same period. At the same time, manufacturing output, as measured by real value added, increased by 41%. Thus, manufacturing energy use was essentially decoupled from output during the 1970s and 1980s through reduced energy intensities in the various industry groups that comprise manufacturing and through shifts in the structure or mix of output away from energy-intensive industries.

Of these two factors, reduced energy intensities were the more important. Between 1973 and 1988, intensity reductions would have driven down sectoral energy use by 32% if the level and composition of output had remained constant. Structural change—or shifts in the mix of products produced—also had significant impacts on energy use. The share of manufacturing output generated by five energy-intensive industry groups—iron and steel; non-ferrous metals; paper and pulp; chemicals; and stone, clay, and glass—fell from 24 % in 1973 to 22% in 1988. All in all, this change would have reduced energy use by 11% if the total level of output and the energy intensities of each industry group had remained constant.

The increases in the price of oil that occurred in 1973 and 1979 caused manufacturing oil intensity to fall by 70% between 1973 and 1988. While the substitution of electricity and non-oil fuels was one factor behind this trend, direct efforts to conserve oil were probably more important. The analysis shows that the intensity of electricity use was roughly constant even after correcting for changes in the mix of products.

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Economics of Restraining Carbon Emissions from the Developing Countries

J. Sathaye, A. Ketoff, and N. Goldman

This project is intended to examine the economics of restraining carbon emissions on the basis of long-term energy scenarios for developing countries. The scenarios will also provide a context in which to implement the most effective energy strategies for reducing emissions.

The first phase of the project began in FY88 and focused on an end-use approach to developing long-term energy demand scenarios for the developing countries. In the second phase of the project, initiated in early FY89, we established a network of analysts from institutions in several of the largest energy-consuming developing countries to develop scenarios of long-term energy use for each country in order to project greenhouse gas emissions.

Economic analyses of carbon emissions from India and Indonesia were addressed last year. The Indonesia study indicates that by deregulating energy prices and imposing different levels of taxation on fossil fuels, Indonesia could reduce its CO_2 emissions without suppressing the growth of its economy. In the long run, however, these policies cannot cope with the inevitable rise in coal use in Indonesia, due to constraints on domestic natural gas and oil resources. Limiting the growth of coal consumption in the future will require direct technological intervention in the supply and demand of energy and a shift in current energy export and import policies.

The India analysis suggests that while capital constraints on economic development would probably be addressed through efficiency improvement, reducing the foreign exchange burden of oil imports will be far more difficult.

We also proposed a coupon system that would allow carbon-restraining technologies to be transferred from the industrialized to the developing world.

Additional analysis of the India options is being completed. Similar analyses are also being conducted for China, Brazil, and Nigeria. These will be reported next year.

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Carbon Emission and Sequestration in Tropical Forests

W. Makundi and J. Sathaye

Carbon dioxide emissions from tropical forests rival those from energy use in the developing countries. However, estimates of emissions from tropical forests in the literature vary considerably. The Tropical Forestry and Global Climate Change research network (F-7) was established in 1990 during a meeting of the Intergovernmental Panel on Climate Change, held in São Paulo, Brazil. The main objectives were to improve the precision of the estimates of emissions from tropical forests and to identify and study the response options in the forestry sector. Unlike past methods of estimation, we have relied on a network of participants from seven developing countries to prepare estimates of emissions and sequestration of carbon in their countries using a spreadsheet model that was developed at LBL. The countries are Brazil, Mexico, Indonesia, Malaysia, Thailand, China, and India. By 1990, these countries were estimated to represent about two-thirds of the annual deforestation of closed moist forests.

The deforestation rate for 1990 seems to have substantially declined from the high levels of 1987 in many of these countries. The new estimate for corresponding emissions from the participating countries is about half of the earlier estimates. Proportional projection of these estimates to the tropical biome shows that the total emissions are between 1.1 and 1.6 billion tonnes of carbon per year, with working average of 1.35 billion tonnes, which is significantly less than other estimates. Whereas the current estimates for Indonesia, Malaysia, China, and Thailand are higher, those of Brazil, India, and Mexico are lower than in most other recent estimates (Figure). In China, carbon dioxide emissions from forestry are considerable, although the amount is about half of the 1980 level. Some countries such as China, Malaysia, and Indonesia have large human-grown plantations which sequester large amounts of carbon. Emission and uptake estimates for Nigeria are under preparation.

Response options to increase carbon sequestration and/or reduce emissions at a net economic benefit and their potential consequences are being investigated at present. A workshop will be held in April, 1992, to discuss the progress and results of the economic evaluation. Future plans include completing the economic and policy evaluation of response options, refining the carbon estimates and extending the work to other forest-based greenhouse gases, and evaluating the feasibility of tradable emissions rights for each participating country.

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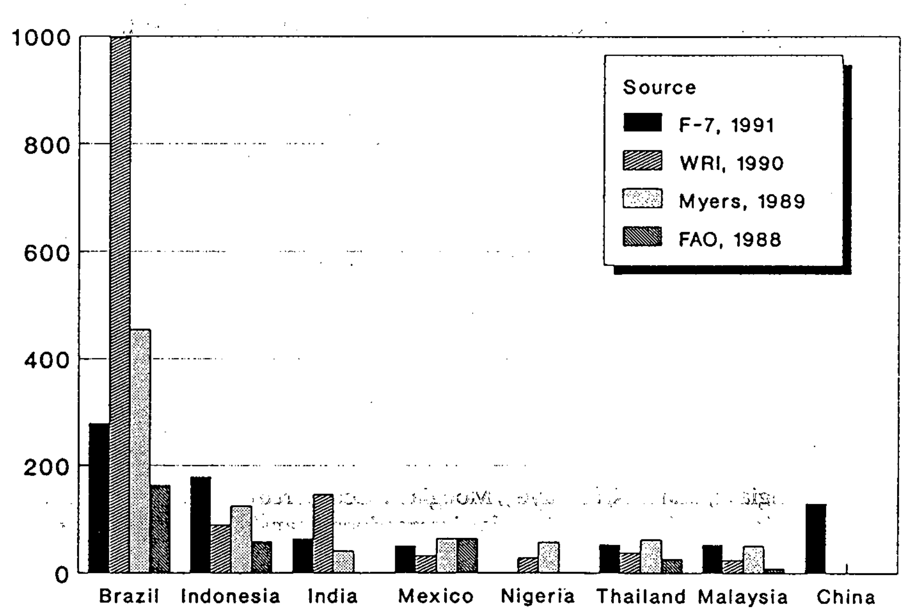

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Figure *A comparison of carbon emissions from forestry in F-7 countries, 1988-1990.*

Urban Energy Use: Saturation and Fuel Transition in the Developing Countries

J. Sathaye and S. Tyler

This project has investigated the transition in household fuel use in cities of the developing countries from traditional biomass fuels to fossil fuels and electricity. Household energy consumption in several cities was surveyed by each of five research teams at institutes in Hong Kong, India, China, the Philippines, and Thailand. The objective of the research was to relate patterns of fuel use to differences in household characteristics such as income, size, location, and access to fuels. In addition, a limited sample of indoor and outdoor air quality measurements will help show the relative exposures of different types of households to airborne combustion products.

Surveys in the countries were sponsored by the International Development Research Center in Ottawa, Canada. LBL has been responsible for project development, provision of technical advice and support to the Asia-based research teams, and overall project coordination. LBL organized three workshops in Asia as part of the project and conducted cross-national comparative analysis of survey findings as they became available.

Chinese households use the least electricity among the households surveyed in these countries. Use of small ampere wiring and fuses in China constrains electricity consumption. Higher efficiency appliances and frugal use of electricity allow households to enjoy the same amenities as in other countries at much reduced electricity consumption.

Refrigerator electricity consumption is closely related to the size of the refrigerator and the household. Other variables such as indoor temperature did not turn out to be significant. Water-heater consumption was closely related to household size and to the capacity of the water heater.

The survey findings confirm that household energy expenditures increase with income, although as a proportion of income they decline. Fuels expenditure as a proportion of income of poor households varies from only 1% in Beijing to 10% in Pune, India.

Economic analysis of the potential for improving energy efficiency of household appliances suggests that cost-effective improvements are possible and efficiencies of many appliances could be improved by as much as 30%. However, testing of the energy performance of appliances is lacking and test centers are essential to estimate appliance efficiency and to evaluate the economic effectiveness of energy-saving appliances.

The survey findings also included data on transport and air pollution. These results will be reported next year.

Reference

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Residential Energy Use and Conservation in Venezuela

A. Ketoff, O. Masera, and *M.J. Figueroa*

We are conducting a study in Venezuela on residential energy use and conservation. The project consists of a survey and an analysis of household energy use in Venezuelan cities covering almost 50% of the country's urban population. The goal is to provide appropriate recommendations for energy conservation and fuel-switching programs that will reduce household energy demand and increase the residential gas market share in the country (Figure).

Results of the surveys show that basic usages of electricity, lighting, television, and refrigeration are diffused in almost all households and that clothes washers are found in more than 75% of urban dwellings. (Air-conditioning is diffused only in few hot climate cities.) Hot water, on the other hand, is available in less than 50% of the dwellings and appears to be a potential market for natural gas. However, the use of electricity for water heating is rapidly diffusing as a result of low electricity prices and the limited extension of the natural gas grid. Less than 2% of the households surveyed are using gas water heaters.

Other results indicate that the intensity (i.e., unit consumption, of energy use for refrigeration and hot water) is high compared to consumption in other cities of the developing countries (e.g., Brazil and Indonesia) and is even higher than in several European countries. This appears to be a consequence of the quality and size of the appliances available in the country, mostly oversized devices of old, obsolete design.

This study examines viable policy options for increasing the market penetration of natural gas and improving the efficiency of appliances. To maximize the return of the gas grid investment, the national gas utility must increase the acceptability of gas as a fuel for cooking and heating water in higher income homes. Policy action directed toward appliance manufacturers, on the other hand, appears to be the best way to increase appliance efficiency. At the same time, subtle action is necessary to promote efficiency as a "status symbol."

The extremely low prices of energy in Venezuela appear to be the major obstacle to an effective energy conservation policy in that nation. Although there are long-term plans to increase the prices for electricity and gas, energy prices in Venezuela are still among the lowest in the world. A program of rebates for efficient energy-using appliances might be necessary to encourage successful diffusion in an environment of low energy prices.

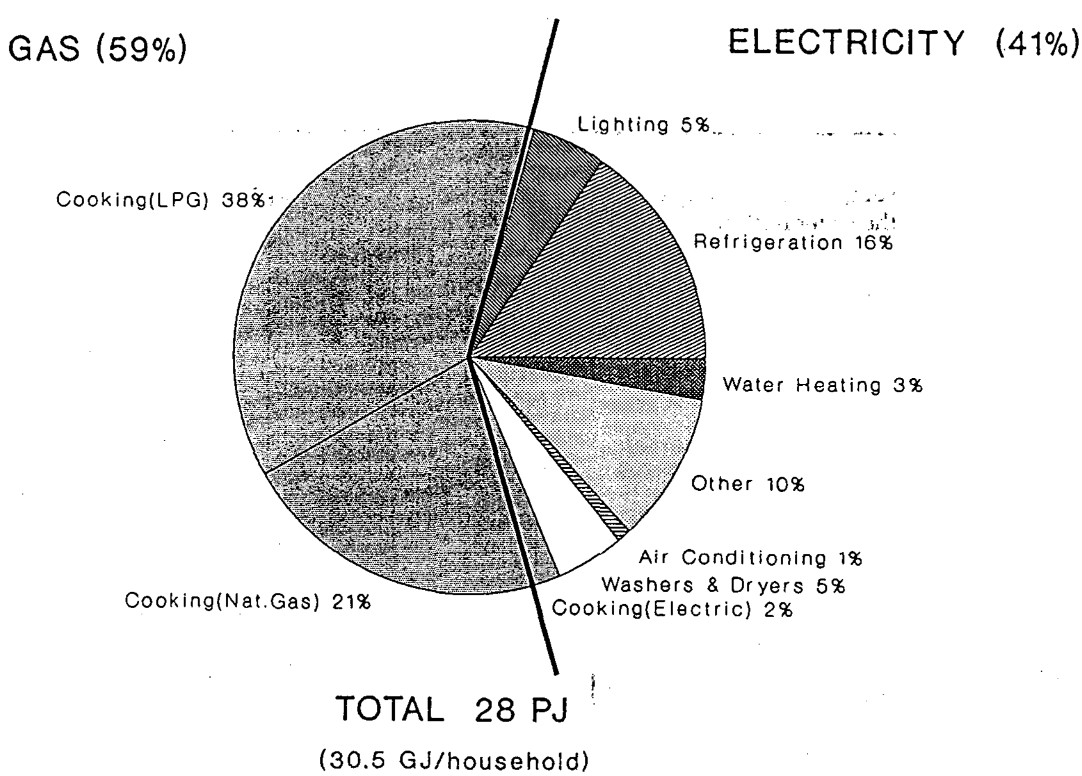

Figure *Energy consumption by end-use in Caracas, 1988.*

Sectoral Oil Transitions and Sustainable Use

J. Sathaye and L. Lee

Securing a reliable oil supply at a reasonable price to satisfy rapidly increasing indigenous demand is of pressing concern to developing countries. For oil-importing countries, this concern is compounded by a shortage of foreign exchange to pay for imported oil. In populated oil-exporting countries, it stems from the rising indigenous demand which may outstrip the country's production capability in the future. In both importing and exporting countries, the severe environmental problems created by oil use in urban areas adds to these concerns.

This project explores the use of oil today in the larger developing countries. It examines the future use of oil in these countries and highlights the macro-economic problems that will be exacerbated. It describes the transition away or towards increased oil use in each end-use sector. Recognizing the potential for altering this transition, we present alternatives that would help to better manage the increasing demand for oil.

There are three important transitions underway in the residential sector. The first is the increased use of kerosene and liquid petroleum gas in place of biomass, and the second is the increased use of gaseous fuels in place of oil. The third transition is the increased use of electricity, which has an indirect but important bearing on the use of diesel fuel for peak electricity generation.

The important transition in the transport sector is the rapid rise in the acquisition of personal vehicles in the Asian countries. The fuel mix is unlikely to alter much between now and the year 2025 unless concerted efforts are made to use more natural gas. Vehicles will become more fuel-efficient in the future, but oil use, driven by increased vehicle ownership and economic activity, will nevertheless increase severalfold.

Efforts to use less oil in the industrial and electric power sector result in reduced share of oil use in the long run. But the increased level of industrial output and electricity generation will still lead to higher levels of oil use.

Overall, oil demand in developing countries is estimated to increase by a factor of four between 1985 and 2025. The increased demand for oil will also require that more than twice the current share of gross domestic product (GDP) be allocated to oil supply in 2025. For the oil-importing countries, which are already short of foreign exchange, this would not be a palatable proposition. Efforts to curtail oil demand will still result in a higher share of GDP than that of today. The results reported here indicate that governments need to institute ways to use oil more efficiently—and to do so immediately—in order to permit economic growth to continue at desired levels.

Reference

Sathaye J. Sectoral oil transitions and sustainable use. In: *Seminar Proceedings: The Role of Petroleum in Sustainable Development. January 7-11, 1991, Penang, Malaysia.* Publication No. 1. PETRAD, International Programme for Petroleum Management and Administration, 1991, pp. 120-141.

Energy-Efficient Transportation in Brazil: Prospects and Barriers

A. Ketoff

In this study, we analyze the prospects for and barriers to long-term efficiency improvements in a developing country, taking Brazil as a case study. Brazil has, among developing countries, one of the highest levels of private car ownership and also a well-developed car-manufacturing industry. Additionally, the country's fuel-switching policy, favoring the substitution of sugarcane alcohol for gasoline, makes it an interesting case to analyze in view of future prospects for energy efficiency.

Several factors are contributing to the rapid growth of transport demand in Brazil, the key one being the increasing urbanization of the population. Large cities—twelve have more than one million people and two have more than ten million—require extensive public transport systems to guarantee personal mobility. Additionally, the growth of cities being faster than the development of infrastructures, freight is almost completely transported on wheels.

To face the increasing transport energy demand and the increasing cost of oil imports, Brazil undertook in the late 1970s a major program of fuel substitution. Gasoline was mixed with 22% ethanol for use in standard cars and hydrated alcohol was used in appropriately converted vehicles. By 1989, half of the energy used for cars was coming from alcohol which was a considerable success for the Proalcool program. More than 30% of the car fleet was running on alcohol, thanks to the rapid diffusion of a technology developed by local car manufacturers. As alcohol substituted for gasoline in the light vehicles fleet, diesel became the mandatory fuel for heavy trucks and buses, further reducing gasoline demand.

While reducing gasoline imports, fuel substitution has acted, on the other hand, as a barrier to improvements in the fuel efficiency of the Brazilian vehicle fleet. The inconsistent quality of gasoline, varying in alcohol content from 5% to over 30% depending on the alcohol supply, has caused improper tuning of the majority of the car fleet. Conscious of the problems created by the low quality of fuels, car manufacturers produced larger engines and avoided introducing more efficient vehicles, as they would require fine tuning to operate properly.

Among the barriers to vehicle efficiency, poor conditions of roads and highways forced the manufacturers to reinforce chassis and suspensions, resulting in increased weight. On the other hand, an historical policy of import quotas has limited the introduction of technological innovation in vehicles, particularly the use of electronic injection. As a result, Brazilian cars are heavier and less powerful than their sister European models. According to two major local manufacturers, the additional cost for larger engines and stronger structures on "Brazilian versions" is about 25% of that of the original model, while the efficiency is around 20% lower. The best available Brazilian car has an average performance of 31 mpg, while the best model available in the United States reaches 45 mpg (52 mpg in Japan).

Another limit to the efficiency improvement of Brazil's car fleet is the uneven distribution of income in the country. With more and more of its population falling under the poverty level (58% in 1990), Brazil has a shrinking market for new cars (Figure). Most buyers of new cars are upgrading to larger models. As a consequence, the average performance of new models, which improved by around 10% between 1983 and 1987, has remained level since then.

This study concludes that energy efficiency in vehicles will be considerably restrained if major structural reforms are not undertaken in the country. Some of the changes (e.g., regionalization of the alcohol fleet, opening up of technological markets) might be relatively simple to pursue. Others (e.g., bringing flexibility into the refining system, improving road quality, developing alternative transport modes) might be very expensive for the country, but are still necessary for the overall development of its economy.

Reference

Ketoff A. *Overcoming Barriers to Energy Efficiency in Transportation: The Case of Brazil.* Lawrence Berkeley Laboratory Report No. LBL-30444, 1991.

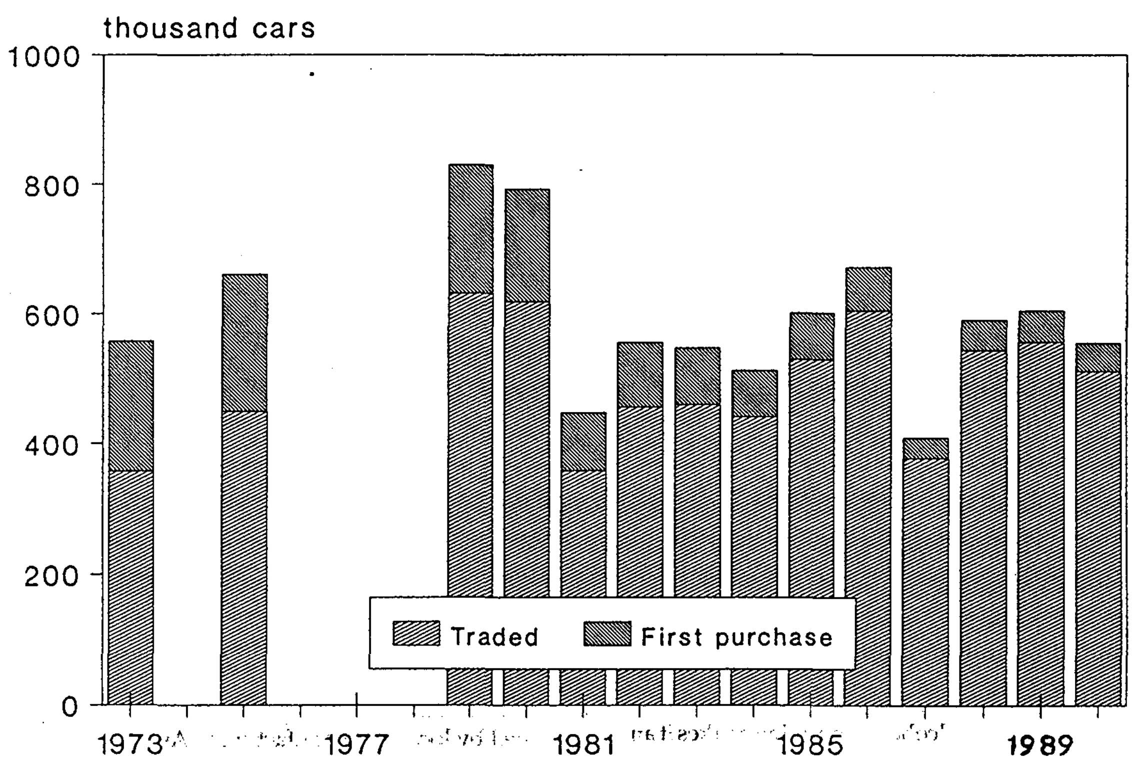

Figure *New car sales by purchaser type; first car vs. traded or second car.*

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