**Title**
FY 1986 ANNUAL REPORT. ENERGY ANALYSIS PROGRAM



**Author**
Lawrence Berkeley National Laboratory

**Publication Date**
1987-03-01

# Lawrence Berkeley Laboratory

UNIVERSITY OF CALIFORNIA

## APPLIED SCIENCE DIVISION



FY 1986 Annual Report

# ENERGY ANALYSIS PROGRAM

March 1987



**APPLIED SCIENCE DIVISION**

Prepared for the U.S. Department of Energy under Contract DE-AC03-76SF00098

LBL-22155

# APPLIED SCIENCE DIVISION ANNUAL REPORT

## ENERGY ANALYSIS PROGRAM

## FY 1986

**Elton J. Cairns**
Head, Applied Science Division
and
Associate Director, LBL

**Mark Levine**
Program Leader, Energy Analysis Program

Applied Science Division
Lawrence Berkeley Laboratory
University of California
Berkeley, California 94720

Prepared for the U.S. Department of Energy under Contract No. DE-AC03-76SF00098

# CONTENTS

# ENERGY ANALYSIS PROGRAM STAFF

Mark Levine, Program Leader
Ronald Ritschard, Deputy Program Leader
Michael Rothkopf, Deputy Program Leader

Hashem Akbari
Patrick Albrand
Anibal de Almeida‡
Barbara Atkinson
Barry Barnes
Sarita Bartlett
John Beldock
Bruce Birdsall
Betty Bratton
John Brown
James Bull
John Busch
Stephen Byrne
Quinsan Cao
Kathleen Carlson
Peter Chan
Ernest Chang
Fu Rong Chang
Alan Comnes
Deborah Connell
Craig Conner
Paul Craig*
Philip Cunliffe
Diana DeBoer
Oliver de la Moriniere‡
Richard Diamond
Joseph Eto
Jean Ferrari
Anthony Fisher†
Denise Flora
Betsy Gardiner
David Foley
Andre Ghirardi
Peter Goering
Charles Goldman
Kathy Greely
Steven Greenberg
William Hanneman†
Elisee Hardy
Angela Harris
Jeff Harris
Diane Hawk
Ali Heydari
Chean Yok Hsui
Yu Joe Huang
Margaret Jackson
Adam Kahane‡
Edward Kahn
Andrea Ketoff
Jonathan Koomey
Florentin Krause‡
Patrick LeConiac‡
Bartlett McGuire†
James McMahon
Margaret Meal
Alan Meier
Stephen Meyers
Evan Mills
Jean-Michel Nataf
Bruce Nordman
Karen Olson
Oystein Olsen‡
Samuel Oren†
Susan Pantell
Park Chun Hun‡
Mary Ann Piette
Christopher Pignone
John Randolph
Imelda Reyes
Rosemary Riley
Henry Ruderman
Jayant Sathaye
Lee Schipper
Nancy Schorn
Renee Slonek
Timothy Springer
Richard Szydlowski
Haider Taha
Mounira Taleb-Ibrahimi
Ann Thorpe
Jeana Traynor
Isaac Turiel
Dorothy Turner
Robert Twiss
Edward Vine
Francis Wenger‡
Debbie Wilson
David Wood
Winifred Yen-Wood

*University of California Davis, †Affiliated staff, ‡Participating guest.

# ENERGY ANALYSIS PROGRAM

## INTRODUCTION

In these times, energy has faded from the public perception as a major national issue. For the first time in more than a decade, energy prices are declining — in nominal as well as real dollars. The world faces a glut of oil and the new "problem" is how to raise prices rather than how to deal with ever-rising prices. The building of baseload power plants, once a rallying point for widely dissenting viewpoints between electric utilities and environmental groups, has faded from the public view as utilities, facing a glut of capacity, resist new projects. The twin "solutions" to the long-term energy problem — renewable sources for the environmentally inclined and synthetic fuels from coal and oil shale for the supply siders — have lost their glamor and the large support of government resources.

Under these new and, in light of the years since 1973, surprising circumstances, what is the role of an Energy Analysis Program at a national laboratory? Do there remain important energy issues of public interest? Does anyone care?

While energy no longer claims headlines or excites politicians to develop grand national energy plans, the importance of energy in the national economy remains undiminished. A substantial portion of total private investment and consumer expenditures in the Nation are devoted to energy each year. Energy remains a cornerstone of our economic security. In the developing world, energy and the financial resources to purchase it are essential prerequisites of modernization and industrial development.

We as a Program are concerned that the Nation may become complacent about our energy future. The present oil glut and low prices will spur oil demand growth. Our studies show rapid growth in oil demand in the developing world, which could well overtake OECD's oil demand shortly after the turn of the century. (By contrast, LDC oil demand was less than 25% of OECD oil demand in 1973.) We foresee a tight oil market, with a return of U.S. vulnerability to the Persian Gulf, in the early to mid-nineties. Utilities will once again need to build base load power plants, and the fundamental conflicts that arise over some of this construction among different groups in society have not been resolved. Renewables and synthetic fuels will not turn out to be a panacea. And, of enormous importance to the entire world, the developing countries are likely to be hardest hit by emerging energy problems and higher prices, jeopardizing development objectives and placing increasing burdens on meeting foreign debt payments.

In this context, the Energy Analysis Program continues to place major emphasis on assessing energy conservation opportunities. The priorities for the Program, as reflected in its research, are: first, energy conservation in buildings, a sector in which significant improvements remain possible and cost-effective; second, assessment of world energy demand, an area of critical importance to an understanding of overall energy policy priorities over time; and third, economic analysis, to gain a rational understanding of how energy policies and programs can more effectively contribute to the well-being of the Nation.

The Program is organized into five groups. The Building Energy Analysis Group is primarily engaged in a wide range of computer simulation studies, leading to the development of simplified tools useful for assessing impacts of measures to increase building energy efficiency. This Group also studies energy use in public housing, an area in which substantial gains are possible. The Building Energy Data Group specializes in collecting and analyzing measured data on the performance of buildings, so as to provide a basis for understanding impacts of real-world programs. This Group has also characterized the performance of energy efficiency technologies in buildings. The Energy Conservation Policy Group has focused its efforts in three areas: evaluation of the impacts of federal appliance energy efficiency standards; developing policies to reduce energy use in commercial buildings in five countries in Southeast Asia; and (3) analyzing economics of electric utility demand-side programs. The International Energy Studies Group has concerned itself with establishing a very detailed data base of energy demand and factors affecting the structure of demand, emphasizing both OECD countries and the developing world. The work includes analyses of specific countries and assessments of the world demand situation. The Resource Market Mechanisms group has studied bidding issues (related to the Public Utility Regulatory Policy Act) and has analyzed factors affecting the energy security of the United States.

In the future, the Energy Analysis Program will continue its efforts in all of the key areas representing present expertise. We expect to maintain our emphasis on building energy studies and envision an expansion of international energy research topics. Additionally, the Program has chosen to develop expertise in a new area: environmental policy analysis.

# BUILDING ENERGY ANALYSIS

## Overview

The Building Energy Analysis Group (BEA) conducts research and analyses on all important issues relating to the use and conservation of energy in residential buildings. The work stresses *whole buildings* rather than individual components viewed separately, in an effort to improve understanding of the tradeoffs among different approaches to achieve increased efficiency of building energy use. The research is intended for two types of use: (1) *to further knowledge* of all aspects of energy use in residential buildings and (2) *to provide research results* in a simplified format to assist builders and building operators to reduce energy use in residences. The work of the Group focuses on four areas:

- Simplified energy analysis methods,
- Energy-efficient and cost-effective cooling strategies,
- Residential building type analysis (single and multifamily), and
- Public and low-income housing.

A major accomplishment of the Group is the development of a simplified computer energy analysis tool (PEAR), which serves as the calculation procedure for the Department of Energy's voluntary guidelines for new residences and the source of energy requirements for the revisions to the ASHRAE 90.2 standard. An important aspect of the microcomputer program is a calculation procedure that considers the energy characteristics of residences with massive walls. An article by Byrne and Ritschard describes the procedure used to calculate the effects of thermal mass in the exterior walls of typical new residences throughout the U.S.

Another important research topic, which was important to the completion of PEAR, was to define and evaluate the relationship between climate parameters (i.e., temperature, insolation, humidity, etc.) and energy use in residential buildings. Huang, Ritschard, Bull, and Chang provide a summary of their findings on the topic of climate variation and energy use for all U.S. climates.

In order to provide an analysis of the incremental cost of building energy efficient homes in the Pacific Northwest, actual costs data from builders and subcontractors was evaluated. In an article by Vine, the total incremental building costs normalized by floor area and by component area are presented.

In addition to gaining an better understanding of the energy performance of new single-family residences, the BEA Group has been conducting research on the topic of existing multifamily buildings, particularly in the public housing sector. Three studies are presented for FY 1986. Greely, Goldman, and Ritschard report on their calculation of energy savings and cost-effectiveness for 43 retrofits, using utility bills and costs data collected from case studies, housing authorities, and utilities. In an article by Mills, Ritschard, and Goldman, the financial impacts of conservation retrofits in case studies are summarized. Finally, as part of an end-use evaluation in multifamily buildings, Vine and associates report on an investigation of domestic hot water consumption in four public housing apartments in San Francisco.

# Thermal Mass in Exterior Walls of Residential Buildings*

*S.J. Byrne and R.L. Ritschard*

This article summarizes an analysis of the impact of various wall and building design characteristics on the energy savings due to thermal mass in exterior walls of residential buildings. Thermal mass effects on annual heating and cooling loads were examined in 12 climates for three types of exterior walls—insulation either inside or outside of the mass layer and with insulation and mass mixed. Using a parametric series of computer simulations and multiple regression analysis, the results were reduced to simple equations that predict the performance of massive walls in typical residences. These regression equations are suitable for use in microcomputer energy analysis programs and other simplified design and analysis tools.

The use of thermal mass has been shown to be an effective means of reducing both heating and cooling loads of residential buildings. The magnitude of the savings depends on a complex interaction of factors including the climate, the amount and physical properties of the mass, and other building design parameters such as the area and orientation of windows, the type of window glass, the natural ventilation rate, and the building thermal integrity. In previous research, we quantified the mass effects for various types of massive walls and incorporated it into our residential slide rule. This slide rule was used to calculate the thermal mass effect, as well as the performance of other conservation measures, for typical building designs and operation conditions. The present research extends the previous work to account for the thermal mass effect due to variations in the building design, including changes that affect solar gain and natural ventilation rate.

## ACCOMPLISHMENTS DURING FY 1986

We have shown the heating and cooling load reduction due to thermal mass in exterior walls to be a result of a complex set of interactions between the amount and physical properties of the mass, the location and amount of insulation in the wall, and building design features that affect solar gain and natural ventilation rate. We have developed an extensive database of DOE-2.1C simulations of a ranch house prototype and then reduced the results to a set of regression equations that account for changes in mass thickness and density and wall U-value for three wall insulation configurations in 12 climates. The following non-linear model predicts the difference in load between a wood-frame wall and a massive wall with the same total wall U-value.

$$\Phi = e^{(\beta_0 \times H_c)}$$

$$\Delta \text{ Load} = \beta_1 + \beta_2\Phi + \beta_3 U_T + \beta_4 \Phi U_T$$

where:

$\beta_{0-4}$ = regression coefficients

$H_c$ = wall heat capacity (Btu/ft$^2$*°F)

$U_T$ = total wall U-value (Btu/hr*ft$^2$*°F)

The load savings for two wall types are shown in Table 1. The results are an indication of the average thermal mass effect in typical houses. Fig. 1 shows the thermal mass effect on a monthly basis for 0.67 ft. (0.20 m.) massive wall. The shaded area represents the difference between a shading coefficient of 1.0 and 0.4. We found the thermal mass effect to be much larger during the months when the outside air temperature fluctuates about the building balance point temperature. During those months, the case with a higher shading coefficient shows a significantly greater savings.

## PLANNED ACTIVITIES FOR FY 1987

In FY 1987, we plan to focus on extending the regressions to include climatic parameters, such as solar radiation, degree hours and average diurnal temperature range as well as building features that affect solar gain and ventilation rate. This will increase the flexibility and accuracy associated with using a simplified correlation technique rather than a comprehensive main-frame simulation program.

Concurrent research in FY 1987 is intended to quantify the actual natural ventilation rate due to wind and thermal forces in a variety of building designs. The results of this work will enable us to more accurately predict the energy savings and the corresponding thermal mass effects due to natural ventilation cooling.

## SUGGESTED READING

1. Byrne, S.J. and Ritschard, R.L. (1985), *A Parametric Analysis of Thermal Mass in Residential Buildings*, LBL-20288.

*This work was supported by the Assistant Secretary for Conservation and Renewable Energy, Office of Buildings Energy Research and Development, Building Systems Division of the U.S. Department of Energy, under Contract No. DE-AC03-76SF00098.

**Table 1.** Total annual heating plus cooling load savings due to thermal mass in the base case house with a 0.67 ft (0.20 m) concrete block wall with insulation outside of the mass layer.

| | Wall U-Value | | | |
|---|---|---|---|---|
| Location | 0.20 Btu/h·ft$^2$·F | 1.13 W/m$^2$C | 0.05 Btu/h·ft$^2$·F | 0.28W/m$^2$C |
| | (MBtu/yr) | (GJ/yr) | (MBtu/yr) | (GJ/yr) |
| Atlanta, GA | 5.2 | 5.5 | 3.0 | 3.2 |
| Brownsville, TX | 4.4 | 4.6 | 3.3 | 3.5 |
| Buffalo, NY | 2.8 | 3.0 | 1.5 | 1.6 |
| Cincinnati, OH | 4.4 | 4.6 | 2.6 | 2.7 |
| Denver, CO | 4.5 | 4.7 | 2.4 | 2.5 |
| Los Angeles, CA | 2.4 | 2.5 | 1.2 | 1.3 |
| Medford, OR | 6.3 | 6.6 | 3.1 | 3.3 |
| Miami, FL | 3.7 | 3.9 | 2.7 | 2.8 |
| Phoenix, AZ | 7.1 | 7.5 | 3.8 | 4.0 |
| San Diego, CA | 2.5 | 2.6 | 1.3 | 1.4 |
| San Francisco, CA | 1.5 | 1.6 | 0.8 | 0.8 |
| Seattle, WA | 1.8 | 1.9 | 0.8 | 0.8 |

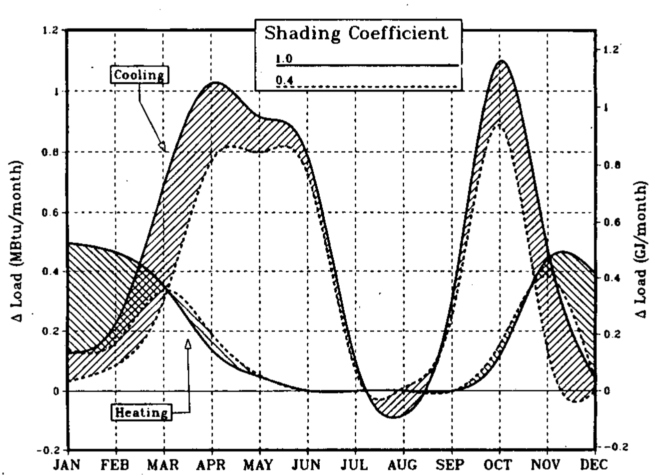



**Figure 1.** Monthly delta heating and cooling loads (Phoenix, AZ) as a function of window shading coefficient for a mass wall with insulation outside of the mass wall. (XBL-871-7)

# Analysis of the Relationship Between Climate and Energy Use in Residential Buildings*

*Y. J. Huang, R. Ritschard, J. Bull, and L. Chang*

Over the past five years, the Energy Analysis Program at LBL has compiled a comprehensive residential energy database using the DOE-2.1A program for five prototype houses (one-story, two-story, split-level, and two townhouses) with three types of foundations in 45 U.S. locations. For each building and foundation type at each location, the database contains roughly 20 simulations showing the energy impact of typical conservation measures such as ceiling, wall, and foundation insulation, different window glazings and areas, and varying infiltration rates.

The analytical effort summarized here involves studying the observed correlation between the database to various climatic parameters. We use the following energy use characteristics from the database in the regression analysis: (1) total heating and cooling loads, and (2) incremental heating and cooling loads (Δ loads) for incremental changes in conservation, i.e., added ceiling insulation or increased window area. The climatic parameters that we investigated include: (1) temperature (daily and hourly heating and cooling degree-days at various base temperatures), (2) humidity (latent enthalpy-days), and (3) solar (heating and cooling insolation-days to various bases). Based on this analysis, we identify certain climatic parameters or combinations of parameters as the most reliable for estimating energy use in residential buildings, and propose several simplified procedures for estimating residential energy use and for extending the DOE-2 database to other locations.

The extensive database of residential energy use provides us an opportunity for correlating building loads predicted by an hourly simulation model to commonly used climatic parameters such as heating and cooling degree-days, and to newer parameters such as insolation-days and latent enthalpy-days. We have emphasized the identification of reliable climatic parameters for estimating cooling loads and the incremental loads for individual building components, such as changing ceiling and wall R-values, infiltration rates or window areas.

*This work was supported by the Assistant Secretary for Conservation and Renewable Energy, Office of Buildings Energy Research and Development, Building Systems Division of the U.S. Department of Energy, under Contract No. DE-AC03-76SF00098.

## ACCOMPLISHMENTS DURING FY 1986

We have found that total heating loads can be estimated with moderate accuracy using the single parameter of variable base *daily* heating degree-days. However, adding a second parameter for heating insolation-hours not only improves the correlation, but makes it possible to use standard base 65°F heating degree-days. Once the effects of solar gain have been separated out, the balance point temperatures for the prototypes and thermal integrities investigated are similar enough to permit the use of standard heating degree-days.

For total cooling loads, reliable estimates require at least two climatic parameters. We found good correlations using latent enthalpy hours either with variable-base *hourly* cooling degree-days modified to omit vented hours, or with base 75°F *hourly* cooling degree-days and base 70°F cooling insolation-hours.

In the analysis of Δ loads, we identified six climatic parameters as the most useful for correlating load changes in different building components (see Table 1).

These six parameters cover the major climatic-driven heat flows that affect a building's heating and cooling loads: conductive and convective heat losses and solar heat gains during the heating season, and sensible, latent, and solar heat gains during the cooling season. The correlations for Δ heating loads are very good for the conductive and convective effects, and adequate for solar gain. The correlations for Δ cooling loads are good for solar gain, adequate for above-ground conductive effects (i.e., ceilings and walls) and infiltration, but in need of improvement for below-ground conductive effects (i.e., foundations).

## PLANNED ACTIVITIES FOR FY 1987

In FY 1987, we will expand on the climate analysis to better understand the relationships between solar climatic parameters and building loads, and the influence of climate on cooling equipment efficiencies. In addition, in support of the current revision of ASHRAE residential energy standards, we are now updating the database using the DOE-2.1C program and WYEC weather tapes. Once that work is completed, a similar regression analysis against climatic parameters will be performed.

## SUGGESTED READING

1. Huang, Y.J., Ritschard, R., Bull, J., and Chang, L. (1986), *Climatic Indicators for Estimating Residential Heating and Cooling Loads*, LBL-21101.

**Table 1.** Climatic indicators for Δ loads in residential buildings.

| Component | Climatic Parameters: Heating | Climatic Parameters: Cooling |
|---|---|---|
| Ceiling, Walls and Foundations | $HDD_{65}$ | $CDHR_{75}$, $CDHRV_{65}$ |
| Infiltration | $HDD_{65}$ | $CDHR_{75}$, $LED_{78}$ |
| Windows | $HDD_{65}$, $HID_{65}$ | $CIDV_{70}$ |

where:

$HDD_{65}$ = *daily* heating degree-days at base 65°F.
$CDHR_{75}$ = *hourly* cooling degree-days at base 75°F.
$CDHRV_{65}$ = *vented hourly* cooling degree-days at base 65°F.
$HID_{65}$ = heating insolation-days at base 65°F.
$CIDV_{70}$ = cooling insolation-days at base 70°F, hours below 78° F and .0116 humidity ratio omitted.
$LED_{78}$ = latent enthalpy-days at base 78°F and humidity ratio .0116.

## Analyzing Measured Savings from Energy Conservation Retrofits in Public Housing*

*K. M. Greely, C. A. Goldman, and R. L. Ritschard*

Annual energy costs for the 1.2 million public housing units in the U.S. exceed one billion dollars. During the last decade, the U.S. Department of Housing and Urban Development (HUD) and local public housing authorities (PHAs) have initiated major conservation programs. Our review of energy conservation work in public housing indicated that in spite of substantial retrofit activity, little documented information is available on energy savings from retrofits.[1] In this study, we calculate energy savings and economic indicators for 43 retrofits, using consumption and cost data collected from case studies, housing authorities, and utilities. These results are compared with savings from conservation measures in privately owned, multifamily housing.

Heating system controls and window measures were the two most frequent retrofit strategies in the housing projects we examined. Median energy savings for all retrofits were 14% of pre-retrofit consumption, or 11.2 MBtu/unit-year; savings ranged from -7% to 62%. A median payback time of 12 years showed the retrofits, as a group, to be less cost-effective than a comparable sample of retrofit efforts in privately owned, multifamily buildings. We also examined the persistence of energy savings for a small sample of buildings for which we have several years of post-retrofit utility billing data; preliminary results suggest that proper maintenance is a critical factor in sustaining energy savings after temperature control retrofits in steam-heated buildings. Finally, we studied qualitative factors that influence the acceptability of retrofits, including effects on comfort, building appearance, and security.

Public housing exists in a quite different setting from that of privately owned multifamily housing. A review of the available data suggests that average energy consumption in the typical public housing unit (of 850 $ft^2$) is much higher than in existing multifamily dwellings. A major study commissioned by HUD estimated annual site energy use for the average public housing unit at 146 MBtu/year (1

*This work was supported by the Assistant Secretary for Conservation and Renewable Energy, Office of Buildings Energy Research and Development, Building Services Division of the U.S. Department of Energy, under Contract No. DE-AC03-76SF00098.

MBtu=$10^6$ Btu).[2] The average multifamily unit (817 $ft^2$) consumes only 77 MBtu/year, based on measured data from the Residential Energy Consumption Survey; this is 47% less than the public housing apartment.[3] Structural factors, such as vintage of the building, fraction of central heating, choice of heating fuel, and household size, explain some of the difference in consumption levels. For example, half of both public housing and multifamily units were built before 1960; however, very few public housing starts have occurred since 1975, while 15% of the multifamily units were built in the post-oil-embargo era, and, as a result, benefit from more energy-efficient construction practices. A higher fraction of public housing units have central heating systems than the existing multifamily stock (52 versus 41%). The oil-heating share is roughly comparable for each sector (20-25%), although electric space heating is more prevalent in the multifamily stock compared to public housing (26 versus 7%), which tends to reduce site energy consumption for the sector. The average number of persons per household is higher in public housing than in the multifamily stock (2.9 compared to 2.3 persons per dwelling unit); household size is positively correlated with higher energy use for domestic hot water and cooking.[4]

The institutional setting for conservation investments in public housing is an extreme example of one of the same barriers that hinders conservation efforts in private-sector multifamily buildings. Most public housing tenants have at least part of their energy consumption included in their rent payment; only 12% of public housing tenants pay for their own electricity, while 33% pay for their own gas. Hence, household energy consumption and energy expenditures are not directly linked. In contrast, almost half of the tenants in multifamily buildings have submetered consumption for at least one energy source (48% are partially or fully submetered). There is anecdotal evidence to suggest that public housing also tends to be less well-maintained than its private counterparts, which means greater losses through the building shell and lower heating system efficiency.

## ACCOMPLISHMENTS DURING FY 1986

We stress that the retrofits studied here are selected examples of conservation efforts within the public housing system, intended to give an example of the possibilities of conservation and the experiences of individual PHAs. Analysis of our sample of 43 retrofits shows that conservation work has produced significant energy savings in the public housing sector, but the effort has not always been cost-effective. Figure 1 illustrates the results for five groups of similar retrofits installed by various housing authorities. A large number of expensive retrofits were carried out under demonstration programs, with mixed results. Preliminary results suggest that proper maintenance is a critical factor in sustaining energy savings after temperature control retrofits in steam-heated buildings. In addition, qualitative factors such as a measure's effect on comfort, building appearance, and security reportedly have a strong influence on a retrofit's acceptability, and therefore, its success.

This study represents an initial effort to summarize measured data on retrofit efforts in public housing. During this project, we have gained a thorough appreciation of the difficulties in evaluating public housing conservation retrofits. We believe that many local housing authorities and HUD still do not see the potential benefits that can be derived from an evaluation of the actual field performance of conser-

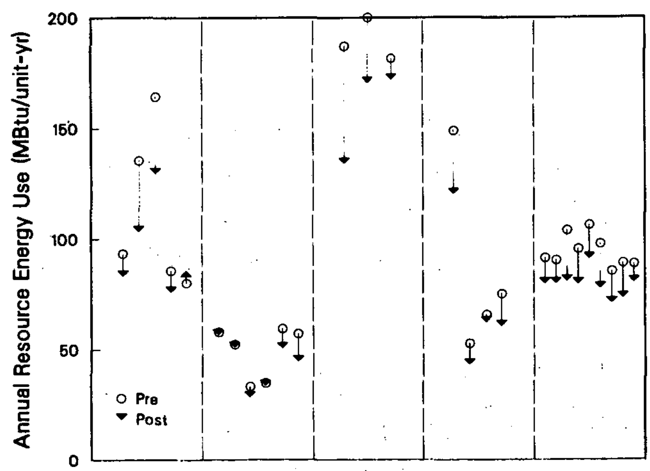



**Figure 1.** Range in pre- and post-retrofit consumption among similar retrofits carried out at different projects. "Shell" measures include attic insulation, weatherstripping, and low-cost domestic hot water retrofits. "Solar DHW" refers to active solar domestic hot water systems. "TRV Controls" are thermostatic radiator valves. Consumption at the San Francisco projects includes energy used for space heat, domestic hot water, and cooking; the oil-heated projects in Trenton and New York include space heat and (estimated) domestic hot water only. (XCG-859-422B)

vation strategies. Documenting measured savings requires that local housing authorities pull together historical energy use, occupancy, and economic and building characteristic data in a systematic fashion. Initiation of this process alone produces the necessary information for a crude energy management accounting system, and provides the basis for local PHAs to track energy use patterns and to set objectives for reasonable consumption levels so they can begin to regain control over their energy expenses.

## PLANNED ACTIVITIES FOR FY 1987

During FY 1987, further research into energy management strategies will be conducted on two levels: PHA energy accounting techniques, and control mechanisms for central heating distribution systems. We will study both the technical and institutional aspects of energy management systems, including implementation, maintenance, computer software, billing policies, tenant involvement, etc.

## REFERENCES


1. Greely, K.M., Goldman, C.A., and Ritschard, R.L. (1986), *Analyzing Energy Conservation Retrofits in Public Housing: Savings, Cost-Effectiveness, and Policy Implications*, LBL-21886.
2. Perkins and Will, and the Ehrenkrantz Group (1980), *An Evaluation of the Physical Condition of Public Housing Stock: Final Report*, H-2850, U.S. Department of Housing and Urban Development.
3. U.S. Congress, House Subcommittee on Housing and Community Development of the Committee on Banking, Finance, and Urban Affairs (1984), "Testimony of Henry C. Kelly," *Review of Federal Policies and Building Standards Affecting Energy Conservation in Housing*, 98th Congress, 2nd session, #98-85, (March 21 and 22, 1984).
4. Energy Information Administration (1984), *Residential Energy Consumption Survey: Housing Characteristics 1982*, DOE/EIA-0314(82).


# Deterrents to Energy Conservation in Public Housing*


*E. Mills, R. L. Ritschard, C. A. Goldman*


During recent years, public housing authorities (PHAs) have attempted to control rising energy costs by initiating retrofit projects. They have used various sources to pay for these conservation measures, including: (1) Department of Housing and Urban Development (HUD) Comprehensive Improvement Assistance Program (CIAP) funds, (2) general operating subsidies, (3) utility-sponsored conservation programs and (4) third-party investments (e.g., from energy service companies). We examined the impact of these various financing strategies on the distribution of retrofit savings and costs between HUD and local PHAs. Our case studies of actual retrofit efforts in two local housing authorities, San Francisco, California and Trenton, New Jersey all show significant energy savings, although this is not reflected in the financial benefits to each party. Our results indicate that the provisions of the Performance Funding System (PFS)—the mechanism through which energy costs are subsidized—often result in a net loss to a local housing authority, even for conservation measures with societal paybacks under three years; hence the present policy reduces the incentive for PHAs to invest in worthwhile conservation measures.

The PFS is used to determine energy subsidies, currently exceeding $1 billion per year, for public housing. The following aspects of the system are crucial for assessing the distribution of retrofit savings between HUD and the PHA.

- Annual consumption is estimated from average use during a three-year "rolling base" period. As a result, reductions in energy use result in gradual subsidy cuts.
- Interim savings are shared by HUD and the PHA on a 50/50 basis.
- In the event of fuel switching (including purchased solar hot water), the rolling base is adjusted to fully reflect the new fuel price.
- New maintenance costs associated with a retrofit are not subsidized.


*This work was supported by the Assistant Secretary for Conservation and Renewable Energy, Office of Buildings Energy Research and Development, Building Services Division of the U.S. Department of Energy, under Contract No. DE-AC03-76SF00098.

The net effect of the PFS rules is that a one and one-half year payback time is required for the PHA to recover its capital and/or maintenance costs. Although HUD recaptures most of the resulting savings they currently do not assist PHAs in contracting with energy service companies. In *shared savings* agreements, for example, the PHA must share the energy savings with a firm that provides capital for conservation improvements; however, under the PFS rules, the PHA does not retain enough of the savings to meet their contract obligation. In *micro-utility* arrangements the firm sells energy to a housing authority at prices below those of the fuel being replaced; however, cost savings from the new fuel (e.g., solar) are immediately recaptured by HUD under the fuel switching clause in the PFS.

## ACCOMPLISHMENTS DURING FY 1986

Our case studies span a range of retrofit types. In San Francisco, the Housing Authority took advantage of a utility-sponsored, zero-interest loan program to install attic insulation, exterior door weather stripping, low-flow showerheads, and water heater blankets in many of the projects that it manages. They also installed solar hot water systems at six senior, low-rise properties, where domestic hot water is supplied by central boilers. This relatively expensive conservation option was financed by third-party investors, who own the solar equipment and sell hot water to the Housing Authority in a micro-utility arrangement. Using CIAP funds the Trenton Housing Authority installed heating system retrofits at two projects. At Donnelly Homes, the Authority replaced central boiler heating controls; at Haverstick they installed high-efficiency boilers.

Except for the solar hot water system, the simple payback periods were under three years. Ignoring investor tax benefits and PHA rebates, the solar domestic hot water system will take over 18 years to pay for itself.

HUD benefits substantially from all four retrofit projects, including the two in San Francisco, for which it did not supply the initial capital (see Fig. 1). However, two cases show a negative financial impact on the local housing authorities: weatherization financed through a utility-loan program and heating controls paid for with CIAP funds.

Because the San Francisco Housing Authority retains only 10% of the savings from weatherization their lifetime energy savings are less than the loan payments, hence the overall negative net present value. Benefits are negative for the Trenton Housing Authority where maintenance costs exceed their share of energy savings. Ironically, savings for this

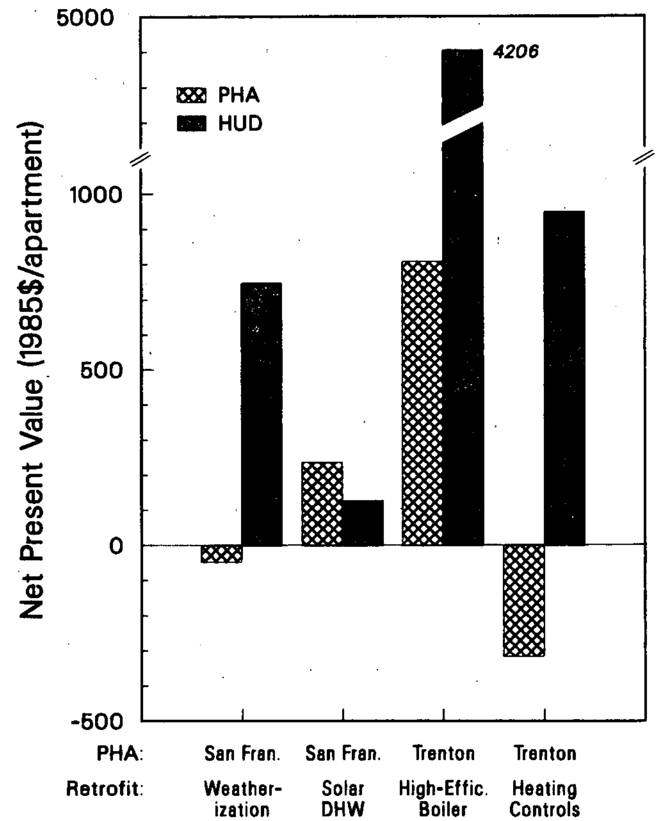



**Figure 1.** Overall financial impact of four retrofits on HUD and the local PHA. (XCG 865-7226)

PHA could have been positive had they neglected maintenance. If the San Francisco Housing Authority had not received special utility rebates, their benefits from the solar retrofit would have been negligible because the fuel switching rules in the PFS immediately reduce subsidies to reflect the lower fuel price.

We tested the sensitivity of our results to less favorable economic assumptions than those used in the base case: a higher nominal discount rate (15%) and shorter retrofit lifetime (10 years). As expected, benefits to HUD decline, although the net present values remain positive. The benefits to local housing authorities do not change significantly.

We have found that under HUD's PFS a local housing authority can lose money as a result of a conservation retrofit, even one with a short payback period. Our results illustrate two ways in which this can happen: the PHA finances retrofits with general operating subsidies and is not reimbursed by HUD, or the retrofit requires more expensive maintenance than the pre-retrofit system (the authority receives no subsidy supplement for new maintenance costs). In the absence of special incentives, retrofits involving fuel switching provide no benefits to PHAs. Because some PHAs lose money, they have little or no incentive to maintain retrofits and thus insure that savings persist beyond the PFS rolling base adjustment period. Alterations to the PFS could stimulate more PHAs to retrofit. Although HUD's share of savings may be lower per project, their overall potential for savings in the stock could be vastly increased.

## PLANNED ACTIVITIES FOR FY 1987

Our work in the coming year will address the opportunities for modifying the current subsidy system to remove the disincentives for PHAs to engage in conservation activity.

## SUGGESTED READING


1. Mills, E., Ritschard, R.L., and Goldman, C.A. (1986), *Financial Impact of Energy Conservation Investment Strategies in Public Housing*, LBL-21741.


# Analysis of Domestic Hot Water Consumption in Four Low-Income Apartment Buildings*


*E. Vine, R. Diamond, and R. Szydlowski*


Domestic hot water consumption is a major source of energy use in multifamily buildings. In contrast to space heating energy consumption, in which behavioral factors compete with the effect of climate, domestic hot water consumption is highly dependent on behavior. Consequently, knowledge of usage patterns is useful in understanding domestic hot water consumption, whether for calculating baseline usage or for estimating retrofit performance.

We investigated domestic hot water consumption in four apartment buildings (a total of 48 units) managed by the San Francisco Public Housing Authority. In each of the buildings, we monitored the performance of the domestic hot water system for six months, and interviewed the residents about their hot water usage patterns. We found the shape of the measured profiles of daily domestic hot water consumption to be different from profiles published in the literature. Figure 1 shows the hourly variation in domestic hot water consumption for a one week period in a nine-unit building. While the average daily consumption in the building varies between 30 and 40 gallons per hour, peak events exceed 150 gallons per hour. We constructed a model of household water consumption based on reported behavior, and found occupant-reported water consuming behavior to correspond well with measured data: building differences ranged from -19% (the model underpredicts) to 12% (the model overpredicts), and the average difference was approximately 12%. We found educational status to be the only significant sociodemographic predictor of estimated household hot water consumption.

We have chosen this topic for several reasons. First, hot water consumption represents a significant use of energy in multifamily buildings: approximately 30% of national multifamily energy use is for domestic hot water consumption (in comparison to 15% in single-family houses). Approximately 22% of the energy consumed in the residential sector is used in multifamily buildings (1.89 quads). This percen-

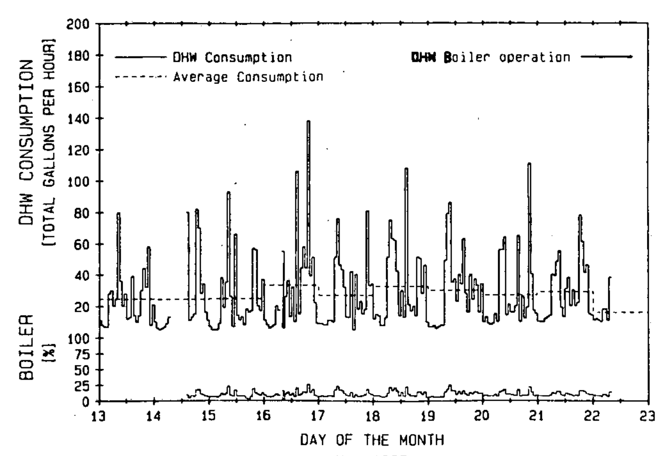



**Figure 1.** Domestic hot water consumption and boiler on-time for 9-unit building, May 13-23, 1985. (XBL-8611-4608)


*This work was supported by the Assistant Secretary for Conservation and Renewable Energy, Office of Buildings Energy Research and Development, Building Services Division of the U.S. Department of Energy, under Contract No. DE-AC03-76SF00098.

tage is greater in cases where space heating needs are smaller—for example, in mild climates, and in new, thermally-efficient buildings.

Second, while behavioral factors compete with the effect of climate in driving space heating energy consumption, domestic hot water consumption is highly dependent on behavior. Hot water consumption is often influenced by cultural and social norms: American households use seven times the amount of hot water used by households in some industrial European countries. In addition, in apartment buildings where hot water is typically master-metered, occupants have no economic incentive to conserve, and, therefore, hot water consumption can be relatively large as well as idiosyncratic. For example, in France, consumption of hot water in apartments with master metering may be as much as 50% larger than consumption in apartments with individual metering. Similar numbers have been observed in West Germany.

And third, knowledge of usage patterns is important in understanding domestic hot water consumption, whether for baseline usage or for estimating retrofit performance. There is currently very little information on how much energy is used for particular functions (e.g., heating, cooling, domestic hot water, cooking, and lighting), and there has been almost no research on the end uses of energy in multifamily buildings. A recent review of domestic hot water energy use examined 15 monitored buildings, only two of which were multifamily buildings. Consequently, it is difficult to optimize the selection of retrofits in multifamily buildings. End-use information is especially important because the potential for saving energy in multifamily buildings is large: retrofit activity in the multifamily sector could save 1.0 quad of energy per year by the year 2000.

## ACCOMPLISHMENTS DURING FY 1986

Very little data exist on end-use energy consumption in multifamily buildings, especially, low-income households. This investigation has shown that average household hot water consumption in public housing, after accounting for leaks, is slightly greater than average consumption in single-family dwellings. We attribute most of this difference to the economic circumstances: the Housing Authority pays for the gas for heating the water.

We were able to model hot water consumption for low-income apartment buildings with moderate success (12% average error). Deviations from our estimates are due largely to leaks in buildings rather than to the behavior of the tenants. Estimated profiles of hot water consumption in these buildings compared very well with profiles from actual data. However, the hot water profiles in these buildings were somewhat different from those reported in the literature. The use of this very simplified model may alleviate the need for detailed monitoring in the long run, although, in the short run, the need for this kind of data collection is needed to verify the results of our modelling in other kinds of buildings.

## PLANNED ACTIVITIES FOR FY 1987

This research has been concluded and no further activities are planned.

## SUGGESTED READING

Vine, E., Diamond, R., and Szydlowski, R. (1986), *Domestic Hot Water Consumption in Four Low-Income Apartment Buildings*, LBL-21771.

# Analysis of the Incremental Cost of Building Energy-Efficient Homes in the Pacific Northwest*

*E. Vine*

The Pacific Northwest is currently experiencing a dramatic and exciting transformation in the way the region produces and consumes energy. Prompted by federal legislation and local initiative, the region is promoting the conservation of energy as the primary new energy resource. In the residential sector, energy efficiency standards for new electrically heated homes have been proposed, and a demonstration program is underway to examine the costs and energy savings associated with building energy-efficient houses. Our findings will be of interest not only to the building industry, government officials, and the general public in the Pacific Northwest, but also to those individuals and organizations outside this region who want to learn from this experience.

In this work, we examined the costs associated with building energy-efficient houses in the Pacific Northwest using real data compiled by builders and their sub-contractors. The data were drawn from a demonstration program, the Residential Standards Demonstration Program (RSDP), which was designed to promulgate the region's new residential energy standards, Model Conservation Standards (MCS).

All four states participating in the RSDP were represented in our analysis of 395 houses (out of 423 RSDP houses): 44 (11%) from Idaho, 67 (17%) from Montana, 59 (15%) from Oregon, and 225 (57%) from Washington. All the houses in the sample were energy-efficient houses (i.e., there were no control houses). Three climate zones were represented: 233 (59%) in zone 1 (the fewest number of heating degree days), 85 (22%) in zone 2, and 77 (20%) in zone 3 (the greatest number of heating degree days). The median floor area of the entire sample was 1883 square feet; the mean floor area was 2047 square feet with a standard deviation of 740 square feet. Most of the houses in our sample were found to be designed to be more energy efficient, on the average, than the standard MCS houses.

Several levels of analysis were used in examining the cost data for the entire sample and for each of the three climate zones: absolute, incremental (the difference between current practice costs and MCS costs), and normalized (absolute and incremental) costs (standardized by floor area and/or component area); and component (e.g., ceiling), sub-component (e.g., attic insulation), and total costs. The discussion emphasizes median costs for they are less susceptible to the positive skew of outliers and, therefore, better represent the central tendency of the sample. We also present other statistical descriptors in our analysis: mean, standard deviation, range, and sample size.

## ACCOMPLISHMENTS DURING FY 1986

Upon examining total incremental building costs normalized by *floor area*, we found the median cost was $2.76/ft$^2$. For the average house in the sample with a median floor area of 1883 square feet, the total incremental cost would be $5,197. It is important to note that these costs include labor and materials, but exclude builder overhead, fees, and profit, and, therefore, the actual incremental costs would be somewhat larger. The median costs for the states and climate zones were as follows: Idaho ($2.15/ft$^2$), Montana ($2.65/ft$^2$), Oregon ($3.35/ft$^2$), Washington ($2.79/ft$^2$), climate zone 1 ($2.84/ft$^2$), climate zone 2 ($2.65/ft$^2$), and climate zone 3 ($2.65/ft$^2$) (see Table 1 for more summary information by climate zone).

Using incremental building component costs normalized by *component area* as a guide, we found that the largest median incremental component cost per square foot was glazing ($2.64/ft$^2$). All other median component costs were below $1.00/ft$^2$: doors ($0.92/ft$^2$), walls ($0.60/ft$^2$), ceiling ($0.34/ft$^2$), floor ($0.25/ft$^2$), air infiltration barriers ($0.12/ft$^2$), and basement walls ($0.00/ft$^2$, i.e., at no extra cost). There was no clear-cut trend in the level of costs among climate zones or states.

The RSDP findings from this cost analysis should be regarded as only indicative for MCS houses for the following reasons. First, due to different types of building codes and code enforcement among the states, the concept of "current practice" is very loosely defined and variable, and, therefore, the calculation of incremental costs, in which current practice costs are subtracted from energy-efficient house costs, is subject to an unknown bias. Second, the cost data itself may be incorrect due to confusion and assumptions made by builders participating in the program. Third, the findings from this demonstration program are not generalizable due to the problem of self-selection in program participation.

*This work was supported by the Bonneville Power Administration, through the U.S. Department of Energy, under Contract No. DE-AC03-76SF00098.

**Table 1.** Total incremental "MCS/As-built" costs per floor area.

| | Mean ($/ft$^2$) | Standard Deviation ($/ft$^2$) | Median ($/ft$^2$) | Minimum-Maximum ($/ft$^2$) | Sample Size |
|---|---|---|---|---|---|
| **Total hard costs** | | | | | |
| All cases | 2.94 | 1.32 | 2.76 | 0.28-13.68 | 391 |
| Climate zone 1 | 2.96 | 1.33 | 2.84 | 0.28-13.68 | 230 |
| Climate zone 2 | 2.90 | 1.29 | 2.65 | 1.22-7.98 | 85 |
| Climate zone 3 | 2.91 | 1.32 | 2.65 | 0.82-7.34 | 76 |
| **Design costs** | | | | | |
| All cases | 0.06 | 0.09 | 0.02 | 0-0.67 | 391 |
| Climate zone 1 | 0.06 | 0.09 | 0.02 | 0-0.67 | 230 |
| Climate zone 2 | 0.07 | 0.10 | 0.04 | 0-0.50 | 85 |
| Climate zone 3 | 0.04 | 0.05 | 0.02 | 0-0.24 | 76 |
| **Loan costs** | | | | | |
| All cases | 0.08 | 0.14 | 0.04 | 0-1.53 | 391 |
| Climate zone 1 | 0.10 | 0.16 | 0.06 | 0-1.53 | 230 |
| Climate zone 2 | 0.08 | 0.14 | 0.04 | 0-0.94 | 85 |
| Climate zone 3 | 0.03 | 0.05 | 0 | 0-0.20 | 76 |
| **Other costs** | | | | | |
| All cases | 0.10 | 0.15 | 0.01 | 0-0.78 | 391 |
| Climate zone 1 | 0.12 | 0.16 | 0.02 | 0-0.78 | 230 |
| Climate zone 2 | 0.11 | 0.16 | 0.04 | 0-0.75 | 85 |
| Climate zone 3 | 0.03 | 0.08 | 0 | 0-0.40 | 76 |

Fourth, this was the first time many of the builders ever attempted to build to this level of energy efficiency using innovative building materials and techniques. And fifth, the incremental costs calculated in this report are for energy-efficient houses that, in general, achieve or go beyond the MCS proposed by the Northwest Power Planning Council.

## PLANNED ACTIVITIES FOR FY 1987

A companion piece to this report is currently being prepared. The new report will examine the costs for a subset of the RSDP sample—"matched pair" houses, two otherwise identical houses except that one was built to superior energy efficient standards while the other one was built to current energy practice. Another report on the occupants of these houses has just been completed.

## REFERENCES


1. Vine, E. (1986), *The Residential Standards Demonstration Program: Cost Analysis,* LBL-21318.
2. Vine, E. and Barnes, B.K. (1986), *The Residential Standards Demonstration Program: Occupant Survey Analysis,* LBL-22409.

# BUILDINGS ENERGY DATA

## Overview

The Buildings Energy Data Group (BED) compiles and analyzes measured energy performance data on buildings and equipment. The Group's goal is to identify building design strategies and end-use technologies that save energy or modify electrical loads, and are cost-effective. We provide these measured results to institutions and persons responsible for improving energy efficiency in the buildings sector. In addition, we use the data to estimate regionwide potential savings from energy-efficient technologies.

The core of BED's activities rests in the Buildings Energy-Use Compilation and Analysis (BECA) series. Each data compilation addresses a sector of the buildings end use:

- New, low-energy homes (BECA-A)
- Retrofits of existing residential buildings (BECA-B)
- New, energy-efficient commercial buildings (BECA-CN)
- Retrofits of existing commercial buildings (BECA-CR)
- Residential water heating systems (BECA-D)
- Validations of computer loads models (BECA-V).

Each compilation is an independent data base, but all rely on the same computerized data base management system (DATATRIEVE). Each data base can be queried so as to produce buildings with similar features, location, function, etc. The article by Goldman and Greely on multifamily retrofits (a subset of BECA-B) is an example of the compilations developed by the Group.

An important research goal of the BED Group is to develop, refine, and promote the wider use of standard "yardsticks" of building energy performance. For automobiles, a dynamometer test yields a single parameter of fuel efficiency (miles per gallon). Unfortunately, one cannot measure a building's energy use under similarly controlled conditions. Instead, we must collect detailed information about the building, including its energy consumption, physical characteristics, and operating schedule. This information permits us to to convert "raw" measurements into standard energy performance indicators. In the past, indicators focused on energy savings and cost-effectiveness; we are now developing parameters that describe peak power savings or, more generally, reshaping of electrical demand profiles. Some of this work is described in the articles by Akbari and by Piette, on measured commercial building data.

The BED Group is also active in two areas that complement the core data compilation effort: primary data collection and conservation potentials studies. In special circumstances, BED measures energy use in specific buildings or equipment. This usually occurs after we have identified significant gaps in available data. The article by Akbari describes how in-place energy monitoring systems (EMS) were used as a highly cost-effective method to collect valuable building performance data. An article by Meier describes laboratory measurements on a group of Japanese refrigerators which allowed us to reconcile U.S. and Japanese test procedures, and develop a simple conversion formula.

The BECA compilations provide a valuable data base from which to estimate the potential for energy efficiency and electric load-shaping which are important elements of least-cost utility planning. The potentials studies typically examine a series of end-use measures, calculate the costs of conserved energy, and develop "supply curves" of conserved energy (or peak savings) to express the aggregate potential for end-use efficiency. The article by Krause describes how we developed supply curves of conserved electricity (and load shape impacts) for Michigan. Related activities include the development of improved, microcomputer-based software to simplify the assessment of energy efficiency potentials. This computer model is linked to a data base on end-use technology characteristics, which emphasizes careful accounting procedures to reflect stock turnover and to aggregate energy and peak savings without double-counting.

In addition to data compilation and analysis, we sometimes take steps to improve the quality of primary data available, through direct participation in monitoring projects or analysis of primary data, to demonstrate new techniques. Two of the following articles describe these activities. Piette applied the BECA-C methodology to a group of award-winning, energy-efficient buildings. Another article by Meier describes the application of techniques used in the BECA-A compilation to normalize for internal gains and inside temperatures in homes. They calculated the energy performance in over 500 new homes in the Pacific Northwest based on measured data.

# A Compilation of Measured Energy Savings in Multi-Family Retrofits*

*C.A. Goldman and K.M. Greely*

We have compiled and analyzed measured data on 141 retrofit projects in U.S. and Swedish existing multi-family buildings. We examined the costs of conservation measures and practices and the savings they generate. In this article, we also discuss the correlation between energy savings and initial pre-retrofit energy intensity, amount of investment, and choice of measures.

The multi-family sector, consisting of residential buildings with two or more units, comprises almost 27 percent of the U.S. housing stock (in terms of household units). Annual site energy use in these buildings is approximately 2.3 quads (1 quad = $10^{15}$Btu) and directly or indirectly costs U.S. households almost $20 billion.

We obtained information on retrofit projects from several data sources, including city energy offices [40], public housing authorities [40], research institutions and national laboratories [25], private building owners/managers [16], non-profit and for-profit energy service companies [14], and utilities [3].† The data collected typically included metered energy consumption, installed retrofit measures and their costs, the price of the space heating fuel the winter after retrofit, and a brief description of the physical characteristics of the building. In most cases, we (or our data source) used the Princeton Scorekeeping Method (PRISM) to analyze energy consumption data before and after retrofit.‡ PRISM estimates a weather-normalized annual energy consumption (NAC) from parameters obtained from a regression of either utility bill or meter readings of the space heat fuel and daily average outdoor temperature. The NAC represents consumption that would occur in a year with typical weather conditions.

Various HVAC system retrofits (heating controls, equipment measures, and altered operation and maintenance practices) are the most popular conservation strategies in our sample of buildings from the Buildings Energy Use Compilation and Analysis (BECA) residential data base. Most buildings in the data base are small to medium size multi-family buildings; 60% are between 10 and 50 units; only 10% are more than 100 units. Retrofit costs are less than $250/unit in 40% of the buildings, which suggests that many building owners confined their retrofit efforts to fairly low-cost measures.

## ACCOMPLISHMENTS DURING FY 1986

Median annual energy savings were 11 MBtu per dwelling unit, or 16% of pre-retrofit energy use. We have found that energy savings are between 10 to 30% of pre-retrofit energy use in 60 percent of the buildings in our compilation. Energy savings are correlated more strongly with energy consumption before retrofit (r = 0.68) than with total cost of the measures (r = 0.37). We found that categorizing each retrofit project by strategy helped explain much of the variation in the amount invested; however, energy savings still varied widely among similar groups. In most cases, investments in excess of $2000/unit do not save enough energy to justify the cost. The 22 projects that invested over $2000/unit had a median payback time of 20 years. Preliminary results for buildings in the data base suggest that some envelope measures (e.g., "shell" packages and window measures) have longer payback periods (12 and 16 years, respectively) than many of the heating system retrofit strategies (1-3 years) as Fig. 1. illustrates.

Large variations are observed in energy savings and in costs per unit of energy saved among similar measures. On average, initial retrofit costs are a lower fraction of annual energy expenditures in our sample of U.S. buildings than in Swedish buildings (0.6 versus 2.1). This difference can be partly attributed to two facts: Swedish buildings have lower pre-retrofit energy intensities than American buildings, and also receive relatively costly shell improvements more often than U.S. buildings. Many conservation investments are attractive from a building owner's perspective: the median real rate of return for buildings in this study is 14 percent, which compares quite favorably with real rates of return from tax-free bonds (3-5%).

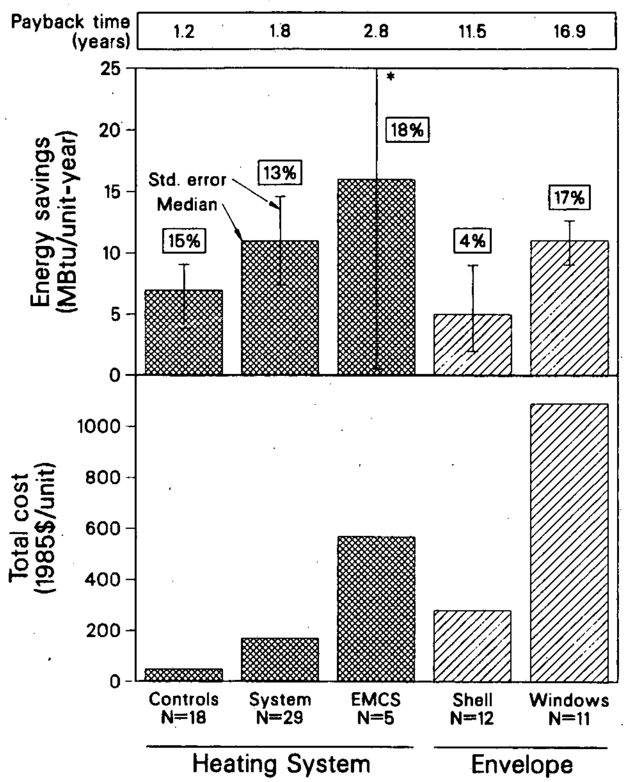
## PLANNED ACTIVITIES FOR FY 1987

We are beginning to compile evidence on the effectiveness of individual conservation measures in specific building and heating system types (e.g., out-

*This work was supported by the Assistant Secretary for Conservation and Renewable Energy, Office of Buildings Energy Research and Development, Building Systems Division of the U.S. Department of Energy, under Contract No. DE-AC03-76SF00098.

†Numbers in brackets represent number of data points obtained from each source.

‡LBL analyzed utility billing data (when available) in all projects except those conducted by the Minneapolis Energy Office and Princeton Center for Energy and Environmental Studies, who did their own PRISM analysis.




* The upper bound for one standard error is at 33 MBtu/unit-year.

**Figure 1.** Energy savings and costs of heating system and envelope retrofits in multi-family buildings. "System" refers to groups of measures that affect the heating or hot water systems. "EMCS" are energy management systems. "Shell" includes combinations of retrofits which reduce heat loss through the building shell. (XCG-863-7118A)

door resets for cold-climate buildings with hydronic boilers). There are several on-going research projects, (e.g., DOE:LBL; Princeton CEES; Gas Research Institute: Center for Neighborhood Technology; Bonneville Power Administration's ELCAP project) in which detailed monitoring (i.e., energy end-use data and indoor temperature measurements) will be used to assess the performance of selected multifamily retrofits. We plan to use the data from these monitoring projects to improve our understanding of retrofits in which there is only whole-building energy data.

## SUGGESTED READING


1. Goldman, C.A. and Greely, K.M. (1986), *Energy Savings in Retrofitted Multi-Family Buildings: New Results from the BECA-B Project*, LBL-22688.
2. U.S. Department of Energy (1985), *Building Energy Retrofit Research: Multifamily Sector,* Office of Building and Community Systems, Washington, DC.
3. Fels, M., (1986), "The Princeton Scorekeeping Method: An Introduction," *Energy and Buildings 9:1.*
4. Office of Technology Assessment (1982), *Energy Efficiency of Buildings in Cities,* OTA-E-168, Washington, DC.

# Primary Data Analysis: Residential Standards Demonstration Program*

*A. Meier, B. Nordman, C. Conner, and J. Busch*

This article summarizes LBL's thermal analysis of the Bonneville Power Administration's Residential Standards Demonstration Program (RSDP).[1] The analysis sought to determine the energy savings for houses built to the Model Conservation Standards (MCS).† We applied techniques developed to support our compilation of new, low-energy homes (BECA-A).[2] A normalization procedure was necessary because the homes differed greatly in their design and operation, yet the savings needed to be estimated for "normal" conditions. The analysis is based on 232 houses built to the MCS and 292 "Control" houses selected to represent current building practice.

## ACCOMPLISHMENTS DURING FY 1986

We performed a "Thermal Pre-Analysis" to determine the extent of distortions in thermal performance during the first few months after the construction of the house. The thermal mass of the floor slab or basement requires several months to achieve a near steady-state condition, thus increasing the apparent energy consumption in the first heating season. In addition, we sought to learn, through simulation, the minimum length of monitoring needed to accurately estimate annual space heating consumption. A "Consumption Analysis" was undertaken to assess differences in energy consumption based on raw triple-meter data, that is, prior to any adjustment for differences in weather, building, or occupant characteristics. This permitted us to assess the incremental value of weekly energy and temperature data in predicting performance.

Finally, we used the "SUBMET" model to normalize the metered space heating energy for differences in floor area, internal gains, inside temperature, and climate.‡ We relied on energy and temperature data from the triple-meters (which monitored space heating, water heating, and appliances) and temperature loggers. We also drew upon surveys and audits to provide floor areas and occupancy data. We found that SUBMET reasonably paralleled the floor-area adjusted Consumption Analysis when similar operating assumptions were used. This suggested that SUBMET's normalization procedures were also accurate.

MCS houses typically used 45% less space heat than Control houses (see Fig. 1). The absolute regionwide savings were about 3.5 kWh/ft$^2$-yr and vary somewhat with climate zone, but the relative savings are similar. The savings change when the assumptions are modified for internal gains, inside temperature, and climate zones. The most reasonable sets of assumptions, including the basecase, yield annual savings above 3 kWh/ft$^2$. The most sensitive assumption is the choice of standard internal gains and the fraction of appliance energy that is converted to useful heat.

The distribution of space heating, as revealed in the standard deviations, was much narrower for the MCS houses. The MCS might reduce the uncertainty in forecasting the demand for electricity used for space heating.

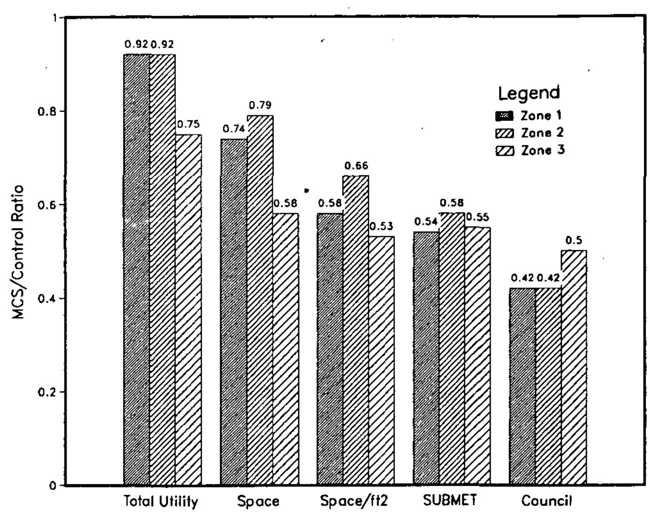



**Figure 1**. The ratio of MCS to Control for several indicators of performance. A ratio of 0.92 indicates that the MCS houses used 92% of the energy of the Control houses. The first three clusters, total electricity use, space heating, and floor-area adjusted space heating, come from the 1985-86 consumption analysis. The last cluster consists of ratios derived from the Council simulations. (XBL-8612-5025)

*This work was supported by the Bonneville Power Administration, through the U.S. Department of Energy, under Contract No. DE-AC03-76SF00098.

†A summary of the RSDP project may be found in a preceding article in this section, *Analysis of the Incremental Cost of Building Energy-Efficient Homes in the Pacific Northwest.*

‡SUBMET (short for "submeter") is a building energy normalization model used in BECA-A to predict annual energy use from submetered energy consumption data.

## PLANNED ACTIVITIES FOR FY 1987

We will investigate the performance of the major energy-saving technologies used in the MCS homes, such as super-insulation, passive solar, heat exchangers, and heating equipment. The goal is to identify designs or technologies that lead to especially low energy use. In addition, we will estimate the cost-effectiveness of the MCS by comparing the incremental energy savings to the incremental cost. We will also try to reconcile energy performance anomalies with occupant behavior.

## REFERENCES AND SUGGESTED READING


1. Meier, A., Nordman, B., Conner, C., and Busch, J. (1986), *A Thermal Analysis of Homes in Bonneville Power Administration's Residential Standards Demonstration Program*, LBL-22109.
2. Busch, J., and Meier, A. (1985), "Monitored Performance of New, Low-Energy Homes: Updated Results from the BECA-A Data Base," *Proceedings of 1985 ASME Solar Energy Division and ASES Engineering Division Annual Meeting*, Knoxville, TN, March 25-29, 1985, LBL-18306.
3. Vine, E. (1986), *Residential Standards Demonstration Program: Cost Analysis*, LBL-21318.


# New Commercial Buildings Data Collection: End-Use Consumption*

*M. A. Piette*

Many commercial buildings are referred to as "energy-efficient," yet detailed performance data are not often published to back up claims. This lack of data is due in part to the difficulties associated with defining, collecting, and analyzing commercial buildings performance data in a consistent fashion, across climates, building types, and usage patterns. For example, to accurately address many questions about energy efficiency one needs energy consumption data more disaggregated than whole-building utility bills. This article discusses end-use data for 12 buildings that have been designed to save energy[1]. Exact definitions of end-use categories differ among data sources. The buildings are a subset from the larger BECA-CN data base (Buildings Energy-Use Compilation and Analysis: part CN) that contains data on over 150 new, energy-efficient commercial buildings[2].

The basic goal of the BECA-CN project is to understand which energy conservation and load shaping techniques have been most successful in occupied buildings. We are interested in developing standardized techniques to assess commercial building energy efficiency based on the information available for particular buildings. Such a framework should include: defining which data should be collected, developing performance parameters for the available data, and comparing results to a relevant data set.

Factors affecting energy use in commercial buildings can be divided into four basic categories: 1) building design (configuration, operation, lighting systems, etc.), 2) miscellaneous equipment loads (computer centers, kitchens, etc.), 3) weather, and 4) occupancy conditions (schedules, number of people, etc.). Since we are concerned with assessing the energy conservation features of the building design, we also must understand the influence of the latter three factors on energy use. Submetered data help us to better understand their influence. These data shed light on the assumptions and results of our past analyses by clarifying where and when energy is used. We compare, for example, the largest end-uses for each building. We also address the question, "Do buildings with daylighting use less energy for lighting than those without?" We would ideally compare the lighting energy use of the daylit buildings with "average" buildings, but sufficient end-use data do not exist for the building stock.

The buildings we have been collecting data on are not typical new buildings; most have won awards for energy conservation, were low-energy demonstration projects, or have been featured in journal articles. We have calculated energy and electric peak demand intensities after grouping buildings according to type, size, climate, and other characteristics

*This work was supported by the Assistant Secretary for Conservation and Renewable Energy, Office of Building and Community Systems, Building Systems Division of the U.S. Department of Energy, under Contract No. DE-AC03-76SF00098.

that influence consumption. As expected, we have found that low annual intensities (kBtu/ft$^2$-year) do not necessarily mean a building is energy-efficient; nor do high intensities always imply inefficiency. For example, the presence of a large computer center or of 24 hour/day occupancy may cause high intensities. Similarly, a very temperate climate may explain a low intensity.

## ACCOMPLISHMENTS DURING FY 1986

The buildings we have studied achieved low energy intensities in various ways. The end-use data greatly increase our ability to understand why the energy intensities are low. The most important findings are:

- Lighting data tend to be the hardest to isolate because of wiring configurations. Fan energy data are also problematic.
- The daylit buildings, as expected, use less energy for lighting than the non-daylit buildings.
- Heating and cooling energy use track average monthly outdoor temperatures in many of the buildings. Lighting energy use tends to be higher in the winter. Fan energy use may also show seasonal variations.
- End-use data allow one to assess important impacts on energy use of large miscellaneous loads, such as kitchens and computer centers. Better data are needed to understand the impact of these large specialized loads.
- Each of the eight buildings plotted in Figure 1 tends to be relatively "energy-efficient" compared to the other sources of comparison data.

## PLANNED ACTIVITIES FOR FY 1987

Research underway can be categorized into two areas. First is in data collection efforts such as ELCAP (End-Use and Load Conservation Assessment Program), which will produce end-use data for the Pacific Northwest[3]. Many utilities are also sponsoring end-use data collection efforts. Another source of data is from future buildings built to the proposed ASHRAE Standard 90.1P. The standard recommends that buildings with electrical service over 250 kVA have electrical distribution systems that allow separation between circuits for: 1) HVAC, 2) lighting, and 3) process loads over 20 kW. Energy management systems are also being studied for their

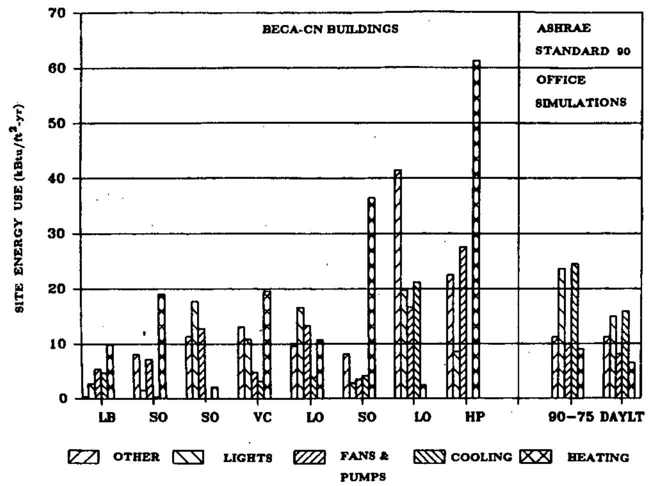



**Figure 1.** Annual site end-use consumption for 8 BECA-CN buildings compared to 2 ASHRAE Standard 90 office simulations. The buildings shown are: a library (LB), 3 small offices (SO), a visitor's center (VC), 2 large offices (LO), and a hospital (HP). The ASHRAE data (90-75 and DAYLIT) are based on DOE 2.1 simulations for a medium office under standard 90-75 and an energy-efficient redesign including daylighting. Service water heating is included in "other" energy use. (XBL 8612-4822A)

capability to provide whole-building and end-use data[4].

The second area is in developing commercial data analysis techniques. Weather normalization research, for example, is showing progress towards developing methods to interpret the effects of climate on larger buildings and those that do not have strictly shell-dominated space conditioning loads[5]. In addition to more end-use data, better economics data are needed to determine the actual cost effectiveness of energy saving features.

These findings are a preliminary look at the end-use data for energy-efficient, new commercial buildings. The large BECA data base effort is an ongoing project; data contributions from readers are welcomed.

## REFERENCES

1. Piette, M.A. (1986), *A Comparison of Measured End-Use Consumption for 12 Energy-Efficient, New Commercial Buildings*, LBL-21894.
2. Piette, M.A. and Riley, R. (1986), "Energy Use and Peak Power for New Commercial Buildings from the BECA-CN Data Compilation: Key Findings and Issues," *Energy Technology*

*XIII: Energy in Transition,* Proceedings of the Thirteenth Energy Technology Conference, Washington D.C., LBL-20896.
3. Joint Project of Bonneville Power Administration Office of Power Management and Conservation, in progress, "End-Use Load and Conservation Assessment Program (ELCAP),"
4. Flora, D. *et al.* (1986), "Methods to Obtain Building Energy Performance Data: Are Energy Management Systems a Promising Source?" *Energy Technology XIII: Energy in Transition,* Proceedings of the Thirteenth Energy Technology Conference, Washington D.C., LBL-20897.
5. Eto, J. (1986), *The Accuracy of Degree-Days in Accounting for the Effects of Weather in Office Building Energy Use,* LBL-22630.

## Building Monitoring Based on In-Place Energy Management Systems*

*H. Akbari*

The number of existing Energy Management Systems (EMSs) in both retrofitted and new commercial buildings is significant and growing. In-place EMSs may be used to gather the additional information of interest for end-use load analysis. Analysis of data provided by in-place EMSs have led us to believe that this technology can be utilized to better understand present energy use, identify opportunities for load management and conservation, and monitor performance.

Energy performance of buildings is often estimated by computer simulation but it must also be verified with actual measured data.[1] In-place EMSs provide a tool to collect these data. Compilation and analyses of hourly energy use, weather, and occupancy information recorded by EMSs can provide a quick and cheap method of obtaining an electrical energy end-use breakdown without actually submetering end-uses such as lighting, heating, and cooling.

### ACCOMPLISHMENTS DURING FY 1986

The capabilities of existing EMSs as a key to end-use characterization of an industrial-commercial building in Milpitas, California, have been evaluated.[2] Spreadsheet programs have been developed to break down the daily and hourly total building electricity use into their major end-use constituents. The calculated total building electricity use agrees with measured data fairly well (within 10%) for the daytime hours of building operation where schedules and occupancy are known (see Fig. 1).

To assess benefits of this technology to building owners, occupants, operators, and utilities, we have reviewed the major characteristics of EMSs currently available on the market in terms of their hardware, software, and intra- and inter-system communications capabilities.[3] Examples of data collection by two types of EMSs have been given to show how the gathered information could be utilized by both building operators and utilities to document energy consumption and peak electricity demand in buildings. We discuss the commonly offered load management software. Finally, communications protocols that allow access to the data resident in the EMS are discussed.

There is a wide choice of equipment on the market that can be used for monitoring and control of energy use, load profiles, and ambient conditions in commercial buildings. This technology has been

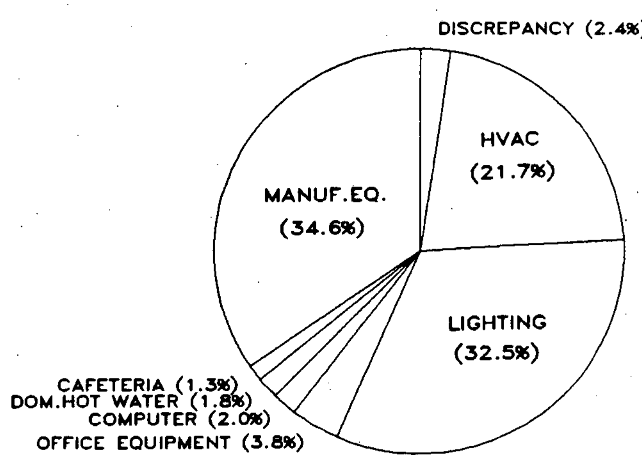



**Figure 1.** Daily end-use breakdown for an industrial-commercial building in Milpitas, CA. The total electricity use for the day is 7425 kWh. (XBL-871-63)

*This work was supported by the Assistant Secretary for Conservation and Renewable Energy, Office of Buildings Energy Research and Development, Building Systems Division of the U.S. Department of Energy, under Contract No. DE-AC03-76SF00098.

built on the solid technical base of the microcomputer industry. Most computer-based energy management systems appear to have adequate hardware capabilities to collect and store the monitoring data needed to evaluate building energy use and load-shaping measures. Many stand-alone monitoring and control systems have hardware and software capabilities to implement demand-limiting strategies. Some of the computer-based control systems specifically address the issue of monitoring of electrical energy end-use and of electricity demand limiting.

Most commercially available systems will require customization to a specific facility and set of measures in order to provide the required monitoring information. Such customizing is, however, common practice even for the conventional control functions.

Even where present, EMS capabilities may not be used to their full potential. Human resources will play an important role in the application of energy management systems to commercial load management. There is some concern about the complexity of the technology. The trend in the building controls industry, however, is strongly toward microcomputer control. There is a period of adjustment as engineers, designers, controls vendors, and building operators become familiar with the equipment.

Our work suggests that EMS-derived data may offer important advantages, in terms of cost and effort versus data quality, compared with conventional approaches now being used to analyze end-use performance in large buildings. Of course, using EMSs for monitoring will not be equally promising in all commercial buildings nor for all data needs. There must be a computerized energy management system already in place, with appropriate sensing, data storage, and communication capabilities. However, we feel that these systems are already becoming standard equipment, especially in buildings larger than 100,000 square feet.

It is possible to take advantage of the data available from even a simple EMS to determine some operating characteristics of a commercial building, especially to understand the way the electricity is used. Hourly EMS data help to indicate the weather dependency of the energy use in the building and can be used as a constraint in load profile estimations where they are invaluable in establishing an accurate end-use breakdown.

## PLANNED ACTIVITIES FOR FY 1987

The results presented here are not the end of this study but represent a first attempt to exploit EMS data. In FY 1987, this approach will be tested with more buildings, including some with submetering to cross-check the results and validate the general method. We also hope to explore buildings in other climate zones, and with other major interior activities. Finally, we would like, in future studies, to quantify the benefits and drawbacks of simplified versus more sophisticated EMSs as the principal source of data.

## REFERENCES


1. Flora, D., Le Coniac, P., and Akbari, H. (1986), *Methods to Obtain Building Energy Performance Data: Are Energy Management Systems Promising Sources?*, LBL-20897.
2. Le Coniac, P., Flora, D., and Akbari, H. (1986), *Energy Management Systems as a Source of Energy Performance Data*, LBL-21892.
3. Akbari, H., Warren, M., and Harris, J. (1986), *Energy Management Systems in Large Commercial Buildings: Monitoring and Control Capabilities*, LBL-21041.

# Least-Cost: The Michigan Energy Options Study*

*F. Krause*

The Buildings Energy Data Group has been involved in least-cost studies for over five years and has been responsible for several conceptual advances, including the supply curve of conserved energy. At the same time, we have applied the concepts to studies of conservation potential in California, the Pacific Northwest, and Texas. The Michigan Electricity Options Study (MEOS) drew upon previous work, while requiring additional methodological developments. For example, we considered the effectiveness of both the conservation technologies *and* the programs to deliver them.

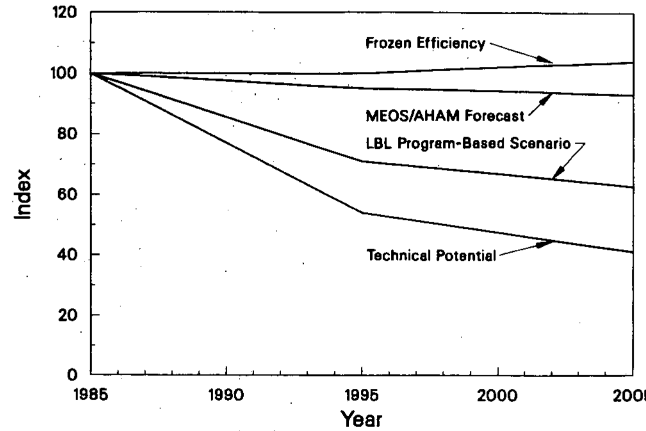



**Figure 1.** Change in residential electricity use, 1985-2005. End-use studies, Consumers Power and Detroit Edison territories. (XBL-8612-12327)

## ACCOMPLISHMENTS DURING FY 1986

LBL was responsible for the assessment of the conservation potential in Michigan's residential sector. Our analysis covered 13 appliance, lighting, and building end-uses constituting 67% of total 1985 residential electricity sales. We investigated more than 100 demand-side technologies and the programs needed to successfully deliver the technologies. The report is not yet complete, but our preliminary findings show that:

- Between now and 2005, Michigan's two largest utilities can build a residential conservation power plant equivalent to the output of one large (843 MW) baseload plant. Almost 80% of this conservation power plant, or 654 MW of baseload capacity equivalent, can be deployed by 1995. The estimate is based on available technology and implementation rates that have actually been achieved by other states and utilities. Moreover, levels of comfort and customer convenience are maintained or allowed to increase. It takes into account such factors as less than perfect installations. (Fig. 1.) The achievable potential estimated by LBL is 33% lower than the consumption levels forecast by MEOS staff under a "business-as-usual" scenario.
- The cost of Michigan's residential demand-side resource is very attractive: with a social discount rate of 3%, the conserved energy from this demand-side power plant can be purchased for 1.5¢/kWh—about half the short-run marginal cost of electricity from the average Michigan baseload plant. This figure includes program administration costs and assumes 100% rebates. The average price of electricity is 6-8 times higher.
- With a 7% discount rate, the basic cost-effectiveness of the residential demand-side resource does not change appreciably. Again, about 80% of the resource can be purchased for less than 3¢/kWh, or at an average cost of conserved energy of 2.1¢/kWh.
- We have also calculated a technical potential based on current and emerging conservation technologies. This technical potential is an upper limit that ignores such program uncertainities such as limited customer participation, less than perfect installation of technologies, etc. It also assumes some technologies which are more advanced, some of which are not cost-effective at this time. We estimate the technical potential is equivalent to 1440 MW of baseload equivalent in 2005, or a saving of 56% compared to the MEOS forecast.
- The same investments in conservation resources bring with them a more than

*This work was supported by the MERRA Research Corporation, through the U.S. Department of Energy, under Contract No. DE-AC03-76SF00098.

- proportional reduction in summer peak demand, resulting in a 12% improvement in the residential load factor at summer system peak. These peak load reductions constitute an important economic additional benefit of the already highly cost-effective energy savings.
- Fuel switching is often a cost-competitive option. In Michigan, customers with electric water heaters represent the largest switchable demand. Based on 1985 figures, some 1500 GWh of consumption and 310 MW of summer peak load could be switched to gas at a cost of conserved energy of less than 2.4¢/kWh.

The likely long-term outlook for a least-cost residential energy future thus consists of continuing reductions in residential electricity consumption.

## PLANNED ACTIVITIES FOR FY 1987

We expect to complete the Michigan study in FY 1987. We will generalize the software so as to permit its application to other states and regions. We will also search for analytical shortcuts in order to reduce the amount of data collection and computation.

## SUGGESTED READING


1. Krause, F. *et al.* (1986), *Analysis of Michigan's Demand-Side Electricity Resources in the Residential Sector*, report submitted to the MERRA Research Corporation.
2. Meier, A., Wright, J., and Rosenfeld, A.H. (1983), *Supplying Energy Through Greater Efficiency: The Potential for Conservation in California's Residential Sector*, University of California Press, Berkeley, California.


# Primary Data Collection and Analysis: Comparison of Japanese and U.S. Refrigerator Testing Procedures*

*A. Meier*

Refrigerators consume the equivalent output of about 25 large power plants in the United States. Energy test procedures are an important element in forecasting refrigerator energy demand, and also permit comparison identification of new technologies. Japanese refrigerators were thought to have incorporated several technical innovations, but differences in test procedures prevented a clear interpretation. Twelve Japanese refrigerators were tested under the U.S. DOE test procedure. We compared the DOE test results to those reported by the manufacturers under the Japanese test procedure.


*This work was supported by the Assistant Secretary for Conservation and Renewable Energy, Office of Buildings Energy Research and Development, Building Systems Division of the U.S. Department of Energy, under Contract No. DE-AC03-76SF00098.


## ACCOMPLISHMENTS DURING FY 1986

Twelve refrigerators were tested according to the DOE procedure. In each case, the DOE test yielded a higher energy use than that reported by the manufacturers. A scatter plot of the annual electricity consumptions of the twelve units is shown in Figure 1. The equation best describing the relation between the DOE and Japanese test is:

$$\text{DOE} = 1.44 \times \text{JPN} + 33.$$

where DOE is the annual electricity use (kWh/year) as determined by the DOE test, JPN is the manufacturers' reported electricity use as determined by the Japanese test procedure (kWh/year), and 1.44 and 33 are constants. The correlation coefficient is 0.98. In other words, the DOE test yields an energy use about 44% higher than the Japanese test plus 33 kWh/year.

## PLANNED ACTIVITIES FOR FY 1987

Our goal is to develop a lab test procedure that is useful in identifying new technologies and reasonably duplicates field consumption. We will continue investigation of refrigerator energy use, both in the laboratory and in the field. The result will be an unusually complete data set on refrigerator energy use. We will coordinate laboratory research at the National Bureau of Standards, the Ontario Research Foundation, and other utilities. These investigations will lead to a better understanding of the sensitivity of new refrigeration technologies to variations in test conditions. At the same time, LBL will assist Bonneville Power Administration in field monitoring similar units in the Pacific Northwest.

## SUGGESTED READING


1. Meier, A. (1986), *Energy Use Test Procedures for Appliances: A Case Study of Japanese Refrigerators*, LBL-22708.

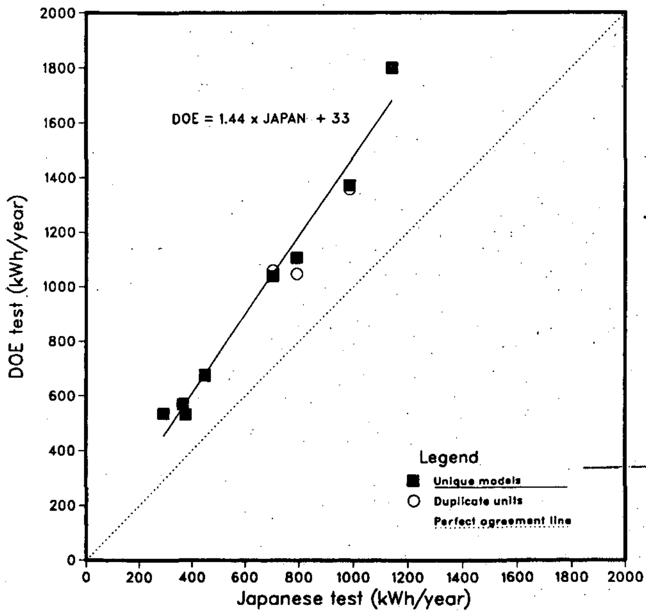




**Figure 1.** Scatter plot of annual electricity consumption of 12 Japanese refrigerators. The Japanese consumption is that reported by the manufacturers, while the DOE was obtained from direct testing. Twelve units were tested, but three were duplicates. The regression line is based on the nine unique models. (XBL-8612-5022)

# ENERGY CONSERVATION POLICY

## Overview

The following seven articles describe specific research work of the Energy Conservation Policy Group. In this article, we wish to describe the broad thrusts and goals of the Group.

The Group is presently working in three general areas: development of energy conservation policy for commercial buildings in Southeast Asia, assessment of appliance energy efficiency standards in the United States, and analysis of impacts of demand-side programs on electric utilities, their ratepayers, and society. All three of these activities have in common the analysis of key public policy issues relating to energy demand. The current work involves working with three very different types of institutions on energy demand policy. The first addresses foreign governments in developing or newly industrialized countries; the second deals with the U.S. federal government; the third addresses decision makers among electric utilities. The varying perspectives among these institutions constitutes a very rich source of understanding of how energy demand policies may be perceived. From our experience, it is perhaps most useful to note the perspective of developing countries. The developing countries with which we have worked have been the most enthusiastic about efforts to implement cost-effective measures to reduce energy use. Unfortunately, these countries have the fewest tools and technical expertise to develop, analyze, initiate, carry out, or evaluate such programs. Nonetheless, over perhaps a ten-year time period, substantial progress in increasing the efficiency of energy use is likely.

What is the role of policy analysis? Why is it carried out?

In many ways, policy analysis—when properly applied—serves to remove from political debate discussion topics that can be resolved with data. For example, in the assessment of appliance efficiency standards, parties in the political arena will make varying and disputed claims about what types of efficiency in products are possible, in what time frames, and at what costs. A responsible policy maker needs the best available information on topics such as these to make decisions. Similarly, for electric utilities, effects of policies on load shapes can be significant and can effect the financial performance of the utility. Utility decision makers need this type of information, and very often they do not have it when making decisions about which programs to support or reject. Further, policies relating to utility demand-side programs can have significantly different impacts when viewed from a utility or from a social perspective. Utility regulators, who are responsible for the public welfare, need to know these types of impacts. Thus, in a broad sense, the major function of policy analysis is the development of reliable information, analyzed in a fair and rational manner, and presented in such a manner that decision makers can use it. Uncertainties in information and analysis methodology also need to be captured and properly presented.

What are longer term objectives of the Group?

First, we anticipate continuing efforts in the areas of past research. The three general areas all remain active and important topics, with many basic questions as yet unanswered and policy not yet formulated. For example, in the appliance standards area, we have gained considerable new knowledge about the energy efficiency decisions in the market; nonetheless, there is much that we do not know. Understanding market behavior is very valuable for assessing impacts of policies, analyzing different types of policies, and reducing uncertainty about growth in energy demand (a factor that affects a very wide range of energy decisions). We also have as an objective the expansion of the work on energy conservation in South-East Asia to other developing countries of the world, as we believe that there is considerable and broad interest in such topics. An important new activity highly worth pursuing involves investigating new types of policy initiatives. In this country, we have been through a period (in the middle 1970s) in which major new Congressional thrusts in policy have taken place, there has been experience and learning about which policies and programs have worked and which have not, and this knowledge can be used to explore new approaches. Finally, we believe that some important methodological issues relating to policy analysis need to be addressed. For example, because of limited data availability, very little effort has been devoted to exploring the equity impacts of different policies as distinct from their impact on economic efficiency. Much more work is needed in this and related areas.

# Energy Conservation Policy for Commercial Buildings in Southeast Asia*

*M. D. Levine, B. Birdsall, J. Busch, K. H. Olson, I. Turiel, and M. Warren*

The overall purpose of this project is to stimulate the development and implementation of policies to increase the efficiency of energy use in commercial buildings in five countries in the Association of South East Asian Nations (ASEAN): (1) Indonesia, (2) Malaysia, (3) Philippines, (4) Singapore, and (5) Thailand. This is carried out through training, research projects, analysis and assessment, and information dissemination.

Previous research demonstrated that significant energy savings in commercial buildings are possible. Figure 1 shows the types of measures that can reduce energy costs and the magnitude of savings that can be achieved. This figure makes clear that the largest reductions in energy use are for windows and lighting measures and that the overall reductions are substantial (more than 20% for daylighting alone). These large savings are particularly impressive when one recognizes that Singapore, for which the analysis was performed, already has among the most energy efficient buildings of any place in the tropics, having instituted an energy conservation standard in 1979 and having now achieved full compliance with the standard. For the ASEAN region as a whole, 20% savings (achievable in a ten-year time frame with a payback of two to four years) represents an *annual* electricity savings of about $400 million. (More than one-third of the electricity used in the region is in commercial buildings.)

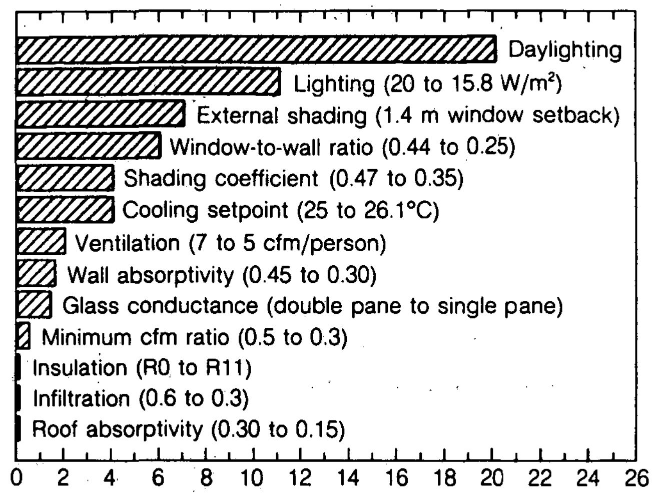



**Figure 1.** Reduction in total energy use (%). (XBL 841-68A)

## ACCOMPLISHMENTS DURING FY 1986

A major training activity brought fifteen government and research personnel from the five Asian countries to LBL for a five-week training program. The training included considerable emphasis on the use of DOE-2 to evaluate the energy performance of commercial buildings. The course also involved lectures on a variety of research topics concerning lighting, daylighting, natural ventilation, air conditioning equipment, data gathering and analysis, and related subjects. In addition to the course at LBL, an energy audit training course was carried out in Indonesia.

Research was initiated on a variety of topics: (1) wind tunnel research was conducted to define parameters to describe wind flow both outside and inside buildings in Asian climates; (2) computer simulations of wind flow around buildings were initiated; and (3) an analysis of the economics of ice storage in commercial buildings (considering both the weather and the load characteristics of the electric utilities in each of the countries) was carried out.

The greatest emphasis in the project concerned the development of energy conservation standards for commercial buildings for Malaysia. Work was done with the ASHRAE Standards Project Committee dealing with commercial buildings, detailed analyses of energy and economic impacts of standards in Malaysia were conducted, and early work on structuring a guide book for commercial building standards was begun. This detailed work is intended to serve as a starting point and guide for similar research in other countries in the region. LBL also played a key role in designing the component of the Thai five-year economic plan dealing with energy conservation in buildings.

Little effort was placed on information dissemination during the year, as this activity will be carried out in later years of the project.

## PLANNED ACTIVITIES FOR FY 1987

The coming fiscal year will see a continuation of the same types of work already conducted. During FY 1987, we anticipate that research groups in each

*This work was supported by the U.S. Agency for International Development through the U.S. Department of Energy, under Contract No. DE-AC03-76SF00098.

of the ASEAN countries will be funded to work collaboratively with the LBL team. Research on daylighting, building monitoring, air conditioning equipment efficiency, natural ventilation, and (particularly) computer simulations to provide a basis for policy development is expected to go ahead jointly between LBL and various research centers throughout ASEAN.

# Analysis of Federal Appliance Energy Efficiency Standards*

*M. D. Levine, P. Chan, J. McMahon, H. Ruderman, and I. Turiel*

LBL is responsible for an integrated analysis of the impacts of federal appliance energy efficiency standards. The research involves a detailed assessment of impacts on consumers, manufacturers, electric utilities, and on the nation as a whole. Figure 1 presents an overview of the overall analysis methodology.

## ACCOMPLISHMENTS DURING FY 1986

The achievements during FY 1986 can best be divided into the following topics: (1) engineering studies, quantifying efficiency improvements of different design options and their costs of production; (2) improvements in methodology for forecasting residential energy and appliance efficiency; (3) assessment of impacts of appliance standards on manufacturers; and (4) other. We summarize briefly the major accomplishments in each of these areas.

### Engineering Analysis

A survey was conducted that identified all the major options for increasing the energy efficiency of residential appliances (including space conditioning equipment).[1] This survey provides a common basis for discussing the full range of possibilities for increasing efficiency of residential equipment over the next decade and possibly longer.

A detailed computer investigation of the energy performance of heat pumps was completed.[2] Results of the computer study were compared with experimental data obtained from manufacturers. Parameters of the calculation were modified to obtain results for central air conditioners. The analysis showed that, with a two-speed compressor and other improvements, efficiencies of heat pumps and central air conditioners can be approximately doubled from the average product purchased today.

An effort was initiated to obtain the manufacturing costs of efficiency improvements for all the appliances.

### Forecasting

The forecasting methodology involves the use of the LBL Residential Energy Model, described in an accompanying article by McMahon and Chan. The major advances during the past year involved: (1) a disaggregate study of market share elasticities for space conditioning equipment (describing the change in sales as a function of income, fuel price, and first cost of the equipment); (2) comparison of backcasted efficiencies and sales from the model with historical data; and (3) application of the forecasting model to electric utility service areas.

### Manufacturer Impacts

A detailed assessment of the impacts of appliance standards on manufacturers of heat pumps and central air conditioners was completed.[3] Financial data describing the industry were obtained from various sources, meetings with consultants familiar with the industry were carried out, a computer model describing the financial conditions of the industry was constructed, a simplified model focusing on the key aspects of appliance standards impacting the industry was built, and the model was run for numerous sensitivity cases. The general conclusions of the research were that the major impact of standards was to reduce profits of that segment of the industry that was not as competitive as the price leaders. For this industry, the less competitive segment was estimated to be less than 10% by sales; the overall impact under the most common assumptions was a reduction of profits for this segment of about 30%.

*This work was supported by the Assistant Secretary for Conservation and Renewable Energy, Office of Buildings and Community Systems, Building Equipment Division of the U.S. Department of Energy, under Contract No. DE-AC03-76SF00098.

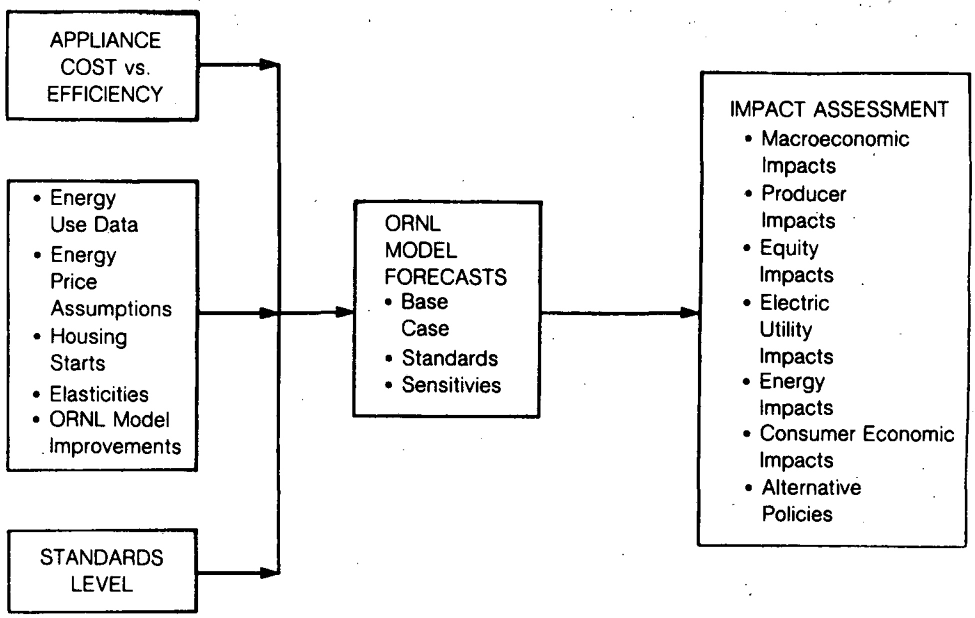



**Figure 1.** Overview of research methodology. (XBL 845-1963)

### Other

Other studies involved in the appliance standards research included the analysis of impacts on electric utilities (described in the accompanying article by Eto, McMahon, Koomey, and Chan), an update of a survey on the penetration and impact of utility appliance rebate programs,[4] and an investigation into appropriate discount rates to use in evaluating federal programs.[5]

## PLANNED ACTIVITIES FOR FY 1987

A major output anticipated in early 1987 is an analysis of the impacts of appliance efficiency standards proposed by Congress under the National Appliance Energy Conservation Act. This Act is the result of a consensus process carried out between manufacturers and environmental groups (especially the Natural Resources Defense Council).

Under present plans, the primary emphases of the research will be: (1) completion of engineering studies of all major products; (2) completion of the cost estimation for all major products; (3) initiation of studies of manufacturer impacts for one or two additional product manufacturers; (4) data gathering and analysis to develop qualitative estimates of impacts on other product manufacturers; and (5) continued refinement of residential energy demand forecasting.

## REFERENCES

1. Turiel, I. (1986), *Design Options for Energy Efficiency Improvement of Residential Appliances*, LBL-22372.
2. O'Neal, D., Boecker, C., and Penson, S. (1986), *Analysis of Efficiency Improvements in Residential Sized Heat Pumps and Central Air Conditioners*, ESL/86-08.
3. Comnes, G. A., Cunliffe, P., Levine, M., and Rothkopf, M. (1986), *Analysis of the Impact on Manufacturers of the National Appliance Energy Efficiency Standards: Central Air Conditioning and Heat Pump Manufacturing Industry*, Draft LBL Report.
4. Levine, M., Carlson, K., Dickey, D., and McMahon, J. (1986), *Effect of Utility Incentive Programs on the Average Efficiency of New Residential Appliances*, LBL-18339.
5. Carlson, K. (1986), *The Social Rate of Discount*, Draft LBL Report.

# The LBL Residential Energy Model*

*J.E. McMahon and P. Chan*

Detailed forecasting models have been used since the mid-1970's to assess potential impacts on consumers of proposed federal energy conservation policies. The first such model intended as a policy analysis tool for the residential sector was the Oak Ridge National Laboratory (ORNL) Engineering-Economic Model of Residential Energy Use.[1] A version of the ORNL Model was moved to LBL and adapted for an analysis of Consumer Product Efficiency Standards in 1979 (see Fig. 1). Public comments during the rulemaking process and new analyses at LBL have suggested many changes in the methodology for simulating residential energy consumption. Some of those changes have been implemented and described in U.S. Department of Energy publications,[2,3] conference proceedings, LBL reports, and previous LBL annual reports describing the analysis of mandatory appliance efficiency standards.

The accumulation of major changes to the method, including a new analysis of market behavior regarding appliance efficiencies, makes the LBL version of the ORNL model unique. The increasing availability of data and the need to analyze issues raised by interested parties in the rulemaking process have driven the transition from the ORNL to the LBL Model. The major methodological differences include: representation of recent equipment efficiency trends, forecasting of future appliance efficiencies based on an analysis of market behavior during the last decade; calculation of appliance replacements based on historical purchases and retirements; the data base for equipment costs and efficiencies; and treatment of heat pumps as competitive space conditioning systems. In addition, the LBL Model has been integrated with other tools for the study of individual electric utilities. (An accompanying article by Eto describes the results of that work.) A recent description of the current model, including all changes to the original ORNL Model, is available.[4]

*This work was supported by the Assistant Secretary for Conservation and Renewable Energy, Office of Buildings Energy Research and Development, Building Equipment Division of the U.S. Department of Energy, under Contract No. DE-AC03-76SF00098.

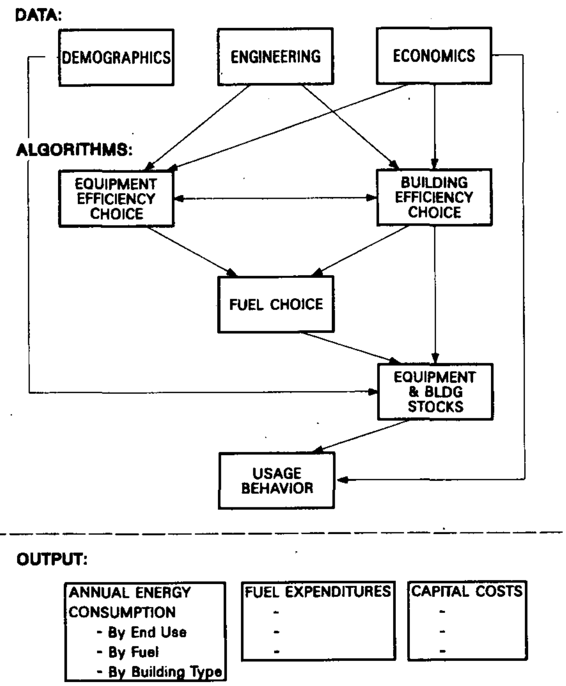



**Figure 1.** Logic diagram showing major components of LBL Residential Energy Model. (XCG 8412-13510)

## ACCOMPLISHMENTS DURING FY 1986

The space conditioning market share elasticities have been replaced. The new method draws on the household-specific data from Annual Housing Surveys (1975-79), the same data used by REEPS (the EPRI-sponsored residential end-use demand model). Furthermore, the new method gives elasticities that vary with the size of the perturbation in the independent variables; links room and central heating choice; and links central air conditioning choice to space heating choice.

The *accuracy of previous forecasts* of equipment efficiency and shipments has been assessed.[5] For many products, the changes in method and data have improved the accuracy. Those areas with the largest remaining forecasting errors have been identified.

A version of the LBL Residential Energy Model is under development for use on personal computers. This greatly increases the transportability of the model and makes it more accessible to a number of users.

Regional disaggregation of the model has been begun. Much of the input data for ten Federal Regions has been gathered.

Equipment prices have been reestimated to include different markups by market segment. This provides a better characterization of the real-world pricing structure, including the importance of the builder market.

We completed 2 additional utility case studies, described elsewhere.

## PLANNED ACTIVITIES FOR FY 1987

New analyses will be performed of national consumer, energy, and market impacts of possible federal appliance efficiency standard levels.

Updated engineering and pricing information regarding alternative equipment designs will be incorporated into the data base as available.

Collection of all necessary data to apply the model to regions of the country will be completed. This will permit characterization of major regional differences in energy end-use consumption patterns, and in impacts of national energy policies. Part of this work will involve analyses of 1980 Census microdata.

In response to the downturn in energy prices in 1986, we plan to research the equipment efficiency improvements occurring in this period of lower prices. The inertia in the system (leading to efficiency improvements even when energy prices decline) will be characterized. This may lead to further improvements in our ability to forecast efficiency improvements over the long term.

## REFERENCES


1. Hirst, E., and Carney, J. (1978), *The ORNL Engineering-Economic Model of Residential Energy Use*, Oak Ridge National Laboratory Report ORNL/CON-24.
2. U.S. Department of Energy, Assistant Secretary, Conservation and Renewable Energy, Test and Evaluation Branch (1982), *Consumer Products Efficiency Standards Economic Analysis Document*, Washington, D.C., DOE/CE-0029.
3. U.S. Department of Energy, Assistant Secretary, Conservation and Renewable Energy, Test and Evaluation Branch (1983), *Supplement to: Consumer Products Efficiency Standards Engineering Analysis and Economic Analysis Documents*, Washington, D.C., DOE/CE-0045.
4. McMahon, J.E. (1986), "The LBL Residential Energy Model: An Improved Policy Analysis Tool," *Energy Systems and Policy 10*(1), LBL-18622.
5. McMahon, J.E. (1986), "Validation of the LBL Residential Energy Model," *Proceedings from the ACEEE 1986 Summer Study on Energy Efficiency in Buildings, Vol. 8,* p. 161.


# Market Share Elasticities of Home Heating and Cooling Systems*


*D. Wood, H. Ruderman, and J. E. McMahon*


Energy demand forecasting models provide estimates of how the market shares of different fuels (electricity, gas, or oil) or technologies (centralized vs. decentralized systems) change in response to changes in the economy. Last year we reported the development of a new technique to estimate own- and cross-elasticities of market share (with respect to capital costs, operating costs, and income) from disaggregate econometric studies. The unique features of our approach are: 1) the derivation of aggregate market share elasticities from individual household data; 2) the linkage of space heating to air conditioning choice; 3) explicit treatment of individual technologies, including heat pumps; and 4) the direct calculation of new market shares due to changes in the explanatory variables, without carrying out an integration.

Like most previous studies, our method starts from regression equations. We perturb slightly the economic factor for which we want elasticities (e.g., price of electricity, capital cost of a gas furnace, etc.). For each household in the database, we calculate from the regression equation the new probability of choosing each technology under the perturbed conditions. Changes in probabilities are averaged across households, giving an estimate of the change in market share. Dividing by the relative size of the perturbation and the original market share gives the appropriate arc elasticity as a function of the perturbation size.


*This work was supported by the Assistant Secretary for Conservation and Renewable Energy, Office of Building and Community Systems, Building Equipment Division of the U.S. Department of Energy, under Contract No. DE-AC03-76SF00098.

We calculate the arc elasticity as a function of perturbation size and fit a least-squares quadratic curve to this data. The intercept of this curve (equivalent to a perturbation size approaching a limit of zero) is taken as our estimate for the point elasticity. The use of arc, rather than point, elasticities allows for more accurate representation of economic effects due to "large" (i.e., non-trivial) changes in income, fuel costs, etc.

## ACCOMPLISHMENTS DURING FY 1986

### Demonstration of the Severity of Aggregation Bias

One principal advantage of our household enumeration method of deriving elasticities is that it provides complete freedom from aggregation bias. This bias occurs in the traditional "naive" approach (i.e., using sample mean values in analytic expressions for the elasticity) due to neglect of covariance relationships among the exogenous variables. The potential severity of this bias (and the corresponding value of our bias-free method) was demonstrated by comparing naive elasticities (calculated at the mean values of the Electric Power Research Institute (EPRI) dataset) and our disaggregate numerical elasticities.[1]

Figure 1 shows the arc elasticities of market share of electric systems with respect to the price of natural gas. Results are shown for two levels of disaggregation: individual households and households grouped within each Standard Metropolitan Statistical Area (SMSA). Our major conclusions (drawn from this and other similar diagrams) are: 1) naive elasticities are unacceptably biased; 2) the bias in arc elasticities at the SMSA level of disaggregation may be acceptable (compared to household); and 3) arc elasticities vary non-trivially as a function of perturbation size.

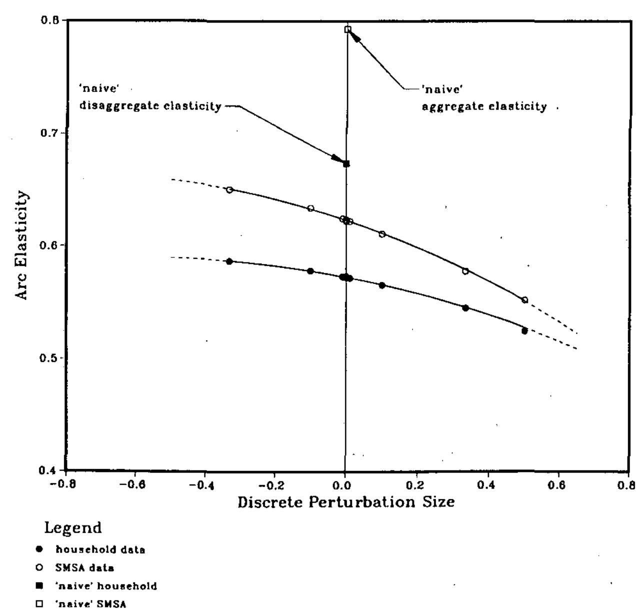



**Figure 1.** Disaggregate and SMSA-aggregate elasticities electric systems with respect to price of gas. (XBL 8612-4923)

### Modifications and Extensions to EPRI Model

Our principal activity this year has been to modify and extend the EPRI model, giving a better fit of the exogenous variables to the data, and correcting some implausible cost calculations. These corrections and extensions are described more fully in an LBL report.[2]

#### *Heat Pump Cost Calculations*

The EPRI models included, as independent variables, the capital and operating costs of each alternative technology. These costs were estimated by using a model of residential thermal integrity and heating loads to estimate the capacity and fuel consumption of each technology in each household, and then local construction costs and fuel prices to translate these into dollar values. Heat pump capital costs seemed quite high (on average, about four times the cost of a conventional air conditioner for the same household), and operating costs somewhat low. Both of these errors could be explained by an oversizing of heat pumps in cold climates.

To rectify the apparent overstatement of capital costs, we proposed a conservative upper bound for any household's heat pump capital costs, and corrected both capital and operating cost of heat pumps for those households violating the bound. Re-estimating the logit regressions, we found significant improvements in the fit of the model to the data.

#### *Cumulative Gas Restrictions*

The period covered by the EPRI (1975-1979) study included several major disruptions in the U.S. energy supply. Many gas utilities were obliged to restrict or even completely prohibit new residential gas service at some point in that period, significantly affecting the market for space heating. EPRI modeled these effects by including binary variables which indicated the presence or absence of three different kinds of restrictions for the gas utility serving each household in the year the house was built. The effects of these variables were all found to be statistically significant.

We investigated whether the effects of gas restrictions extended beyond the period during which they were in force. This could occur either because of a psychological mechanism, as consumers and builders remember the prior curtailments and wish to avoid that possibility in the future, or because of the growth of a sales and service infrastructure for alternative technologies during the curtailment.

We extended the definition of the "gas restrictions" variables so that they were fractional if restrictions had been present in years prior to the construction of a particular residence. We took into account both the duration of the restriction and the time since it was in effect. Changing the gas restrictions variables in this way significantly improved the quality of the fit of the model to the data, and allowed for improved modeling in the LBL Residential Energy Model (LBLREM) of gas market shares.

## PLANNED ACTIVITIES FOR FY 1987

These modifications to the EPRI model give us a high degree of confidence in the elasticities derived from it. These new elasticities, together with some minor extensions of LBLREM (we can now account for predicted shifts in the U.S. population to warmer or colder climates), allow for significantly improved modeling of national residential energy demand. The newly-extended version of LBLREM, together with new elasticities derived from the modified EPRI model, are being used in our ongoing analysis of appliance efficiency standards.

## REFERENCES

1. Wood, D., Ruderman, H., and McMahon, J. (1986), *A Review of Assumptions and Analysis in EPRI Report EA-3409: Household Appliance Choice: Revision of REEPS Behavioral Models,* LBL-20332.

2. Wood, D., Ruderman, H., and McMahon, J. (1986), *A Study of Aggregation Bias in Estimating the Market for Home Heating and Cooling Equipment,* LBL-20333.

# Design Options for Energy Efficiency Improvement of Residential Appliances*

*I. Turiel and M. D. Levine*

This article describes the preparation of information needed for the Department of Energy (DOE) appliance standards evaluation effort. The appliances discussed are refrigerator/freezers, freezers, dishwashers, clothes dryers, water heaters, room air conditioners, home heating equipment, television sets, kitchen ranges and ovens, clothes washers, humidifiers and dehumidifiers, central air conditioners (including heat pumps), and furnaces. In the original standards analysis, completed in the early 1980's, DOE segregated the basic models of each product type into separate classes to which different energy efficiency standards would apply. As mandated by the National Energy Conservation Act, the classes were differentiated by type of energy used, and capacity or performance-related features which provided utility to the consumer and affected efficiency.

The purpose of this work is to identify the changes that have taken place in the products since the early 1980's, suggest possible revisions to product classes, and update the selection of design options for energy efficiency improvement. Product classes are recommended for each of these thirteen product types. Design options to improve energy efficiency are described for each of the product types. Options used in foreign products and in the prototype stage of development are included. Thirteen tables were prepared which contain a list and brief description of each suggested design option.

## ACCOMPLISHMENTS DURING FY 1986

The following listing, for refrigerator-freezers, is a good example of the design options developed for each of the product types.

*This work was supported by the Assistant Secretary for Conservation and Renewable Energy, Office of Buildings Energy Research and Development, Building Systems Division of the U.S. Department of Energy, under Contract No. DE-AC03-76SF00098.

1) *Foam Insulation Substitution in Doors.* Fiberglass insulation is replaced with polyurethane foam insulation. Since polyurethane foam has a thermal conductivity lower than that of fiberglass, this option reduces total cabinet heat leakage.

2) *Increased Door Insulation Thickness.* Foam door insulation is increased to a nominal thickness of 2 inches to further reduce heat leakage.

3) *High-Efficiency Compressor Substitution.* A high-efficiency compressor replaces a conventional design.

4) *Double Door Gasket.* An additional inner door seal gasket reduces heat leakage and air infiltration through the door.

5) *Anti-Sweat Heater Switch.* Cabinet heaters prevent condensation on the cabinet exterior in high humidity. A switch is installed, which can be used in a dry environment to shut off the heaters. Energy savings are realized by eliminating both the heater power consumption and the heat that flows into the cold space from these heaters, which must be removed by the refrigeration system. In baseline units with a hot gas loop, this option includes replacing this loop with electric resistance wire.

6) *Increased Cabinet Insulation Thickness.* Foam cabinet insulation is increased to a nominal 2 inches to decrease heat leakage.

7) *Reduce Heat Load of Through-the-Door Feature.* Improved insulation can be used to decrease the heat leakage and additional power consumption attributable to the through-the-door service feature (ice, water, etc.).

8) *Increased Evaporator Surface Area.* Increased heat exchanger surface area in the evaporator produces more efficient operation of the refrigeration system.

9) *Hybrid Evaporator.* The use of separate evaporators in the refrigerator and freezer compartments increases performance by reducing defrost requirements, fan power consumption and door gasket air leakage.

10) *Adaptive Defrost Control.* The use of "smart" controls to adjust the interval between defrost cycles has the potential for saving significant energy depending on the refrigerator model, usage, and ambient conditions in which the product is located.

11) *Fan and Fan Motor Improvement.* Using new technologies (e.g., dry-film capacitor motors), improved fans can replace the conventional types.

12) *Enhanced Heat Transfer Surfaces.* Improvements in the rate of heat transfer would be obtained by modifying the heat transfer surfaces.

13) *Mixed Refrigerants.* Mixed refrigerants may improve performance through enhanced capacity modulation. Thus far, this option has not provided any practical improvements in performance in refrigerator-freezers.

14) *Fluid Control Valves.* To control refrigerant flow at especially high load conditions, an automatic, adjustable expansion valve instead of the traditional capillary tube can provide better performance.

15) *Improved Foam Insulation.* Improvements in the cell structure and the solid conduction of the foam should result in some overall product energy efficiency.

16) *Evacuated Insulation Panels.* Using evacuated panels in the large planar walls of the cabinet reduces heat transfer through the panels.

17) *Two-Compressor System.* Refrigerator/freezers can operate more efficiently with separate refrigeration systems for the refrigerator and freezer compartments.

18) *Use Of Natural Convection Currents.* The use of natural convection currents (such as in some two-compressor refrigerator/freezers) in lieu of fans eliminates electricity use for the fans and reduces the load on the refrigeration system.

19) *Location Of Compressor And Condensers.* Top mounted compressors and condensers can cool more efficiently, since they can run cooler, due to heat being more readily convected away from the refrigeration system.

## PLANNED ACTIVITIES FOR FY 1987

Future publications will discuss the change in efficiency brought about by each design change and the cost of products of improved efficiency.

## SUGGESTED READING


1. Turiel, I. (1986), *Design Options for Energy Efficiency Improvement of Residential Appliances*, LBL-22372.

# Analysis of the Economic Impact of Demand-Side Programs on Utilities: Nevada Power and Texas Utilities Electric Company Case Studies*

*J. Eto, J. McMahon, J. Koomey, and P. Chan*

The goal of this LBL project is to develop tools and procedures that measure the financial impacts of load shape changes to utility ratepayers and society. The analysis is based on detailed forecasts of energy use by computer simulation models developed at LBL. These models disaggregate both annual energy use and hourly system electric loads at the end-use level for the residential sector. This detail is essential for calculating production and capacity cost benefits, and tariff-class specific revenue changes. We are thus able to combine several analytical procedures commonly employed by the industry independent of one another to yield an integrated assessment of the financial impacts of load shape changes. Figure 1 summarizes the models used and the flows of information between them.

In FY 1986, we analyzed the financial impacts of mandatory residential appliance efficiency standards in the service territories of the Nevada Power Company (NPC) and the Texas Utilities Electric Company (TUEC). Load shape impacts were calculated using the LBL Residential Energy Model, the LBL Residential Hourly and Peak Demand Model, and the DOE-2 Building Energy Analysis Model. Financial impacts were calculated with the LBL Utility Financial Impact Model.

## ACCOMPLISHMENTS DURING FY 1986

The analysis began with detailed forecasts of energy and hourly demands from the LBL Residential Energy and LBL Residential Hourly and Peak Demand Models. Together, these models are capable of producing a twenty year forecast of hourly end-use electricity demands. Though not analyzed in the current study, the LBL Residential Energy Model also accounts for non-electrical energy use and fuel-switching. Where lacking, inputs to describe the thermal integrity of residences were developed with the DOE-2 model. Extensive calibration to historic sales and peak demands preceded these forecasts and achieved good agreement with utility records.

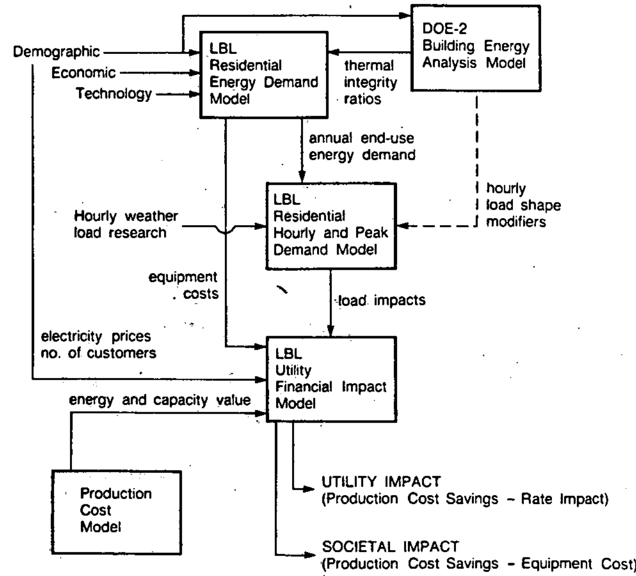



**Figure 1.** LBL Integrated Demand-Side Program Analysis Method. (XBL 867-9852A)

Three levels of mandatory residential appliance efficiency standards with a start date of 1987 were chosen to span a range of load shape impacts. The first mandated modest increases in the efficiency of all appliances. This standard produced a rather even decrease in forecast loads throughout the year. The second was essentially the same standard except for a significantly higher minimum efficiency for central air conditioners. This standard produced dramatic reduction in summer peak demands and, due to the high saturation of central air conditioners, large energy savings as well. The third standard targeted only space cooling end-uses. This standard produced large reductions in peak demands along with modest decreases in energy use.

The benefits to both society and the utility are avoided production costs. For NPC, avoided long- and short-run production costs were calculated with the aid of a production cost simulation model. For TUEC, we relied on avoided cost filings to calculate benefits. The cost to rate-payers is the under-recovery of fixed costs resulting from decreased sales of electricity that must be recovered from customers. For NPC, this cost is, in fact, a benefit since avoided marginal variable operating costs exceed projected retail rates. The utility's weighted average cost of capital was used to discount the net of benefits less costs. The cost to society is the additional cost of

*This work was supported by the Assistant Secretary for Conservation and Renewable Energy, Office of Buildings Energy Research and Development, Building Systems Division of the U.S. Department of Energy, under Contract No. DE-AC03-76SF00098.

the more efficient appliances. A lower discount rate was used to compute the present value of savings to society.

We find that ratepayers and society prefer different appliance standards. While all standards are cost-effective from the utility perspective, the greatest net benefit results from the standards that produce the highest residential class load factor. Conversely, the greatest benefit from a societal perspective results from the standard that produces the lowest increase in class load factor. This last result is sensitive to the cost of more efficient appliances.

## PLANNED ACTIVITIES FOR FY 1987

In FY 1987, we will evaluate the capability of existing integrated planning models for least-cost planning as an alternative to the current approach, which requires linking large stand-alone models.

## SUGGESTED READING


1. Pignone, C. (1985), *The Detroit Edison Company: Financial Impacts on Utilities of Load Shape Changes Project, Stage I Technical Report*, LBL-19750.
2. Eto, J., McMahon, J., and Chan, P. (1985), *The Pacific Gas and Electric Company: Financial Impacts on Utilities of Load Shape Changes Project, Stage II Technical Report*, LBL-19751.
3. Eto, J., McMahon, J., and Chan, P. (1986), *The Virginia Electric and Power Company: Financial Impacts on Utilities of Load Shape Changes Project, Stage III Technical Report*, LBL-19752.
4. Eto, J., Koomey, J., McMahon, J., and Chan, P. (1986), *The Nevada Power Company: Financial Impacts on Utilities of Load Shape Changes Project, Stage IV Technical Report*, LBL-21597.
5. Eto, J., Koomey, J., McMahon, J., and Chan, P. (1986), *The Texas Utilities Electric Company: Financial Impacts on Utilities of Load Shape Changes Project, Stage V Technical Report*, LBL-21598.
6. Kahn, E., *et al.* (1986), *The Effect of Conservation Programs on Electric Utility Earnings: Results of Two Case Studies*, LBL-21098.


# Integration of Supply and Demand Planning: Pacific Gas and Electric Company Case Study*


*E. Kahn, C. Pignone, and A. Comnes*


The goal of this project is to improve the ability to evaluate demand-side programs in the electric utility resource planning process. The project is designed as a case study of the Pacific Gas and Electric Company (PG&E) and is partially funded by them. The analysis is based on the use of an integrated planning model called the Load Management Strategy Testing Model (LMSTM). This model allows a disaggregated chronological representation of electric utility load shapes, integrated with production simulation and the representation of rate and financial data. Because integrated models must approximate the representation in each of their components, there is some concern that the simplification will be excessive and important information will be lost. This concern is greatest for the production simulation element. PG&E is a particularly complex power system whose operation is subject to many constraints and which must integrate a wide variety of resources. Thus the first task of the project involved the calibration of LMSTM's production simulation to the more detailed models used by PG&E for electric resource planning purposes. This task was accomplished in FY 1986. Following the completion of the calibration, we will conduct the resource-planning evaluation based on large-scale implementation of demand-side programs.

## ACCOMPLISHMENTS DURING FY 1986

PG&E supplied LBL with the input and output representations used for electric resource planning with production simulation models. The primary task of the calibration was to aggregate and respecify this data in a form compatible with the input requirements of LMSTM. The aggregation is neces-


*This work was supported by the Assistant Secretary for Conservation and Renewable Energy, Office of Buildings Energy Research and Development, Building Systems Division of the U.S. Department of Energy, under Contract No. DE-AC03-76SF00098, and by the Pacific Gas and Electric Company.

sary because LMSTM simulates seasons compared to the monthly simulation periods used in the more complex models. The choice of season definitions is a user option in LMSTM. For the PG&E system, the principal constraint of this choice involves the substantial annual fluctuations of the hydroelectric resources. LBL chose a specification that captured the main qualitative variations. This choice required a re-characterization of the load data which must be specified in LMSTM as four typical day-types per season. The sensitivity of marginal cost to the precise characterization of the load shape is illustrated in Figure 1. This figure shows that a relatively small change in the off-peak load shape induces a large change in the marginal energy cost is an important feature of the PG&E system.

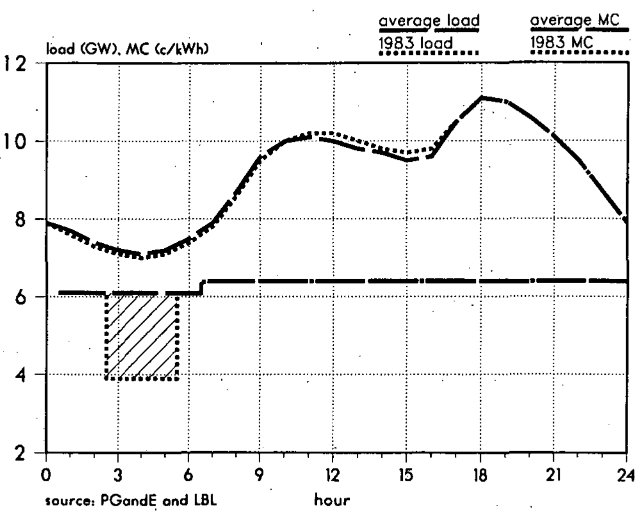



**Figure 1.** Extreme example of marginal cost sensitivity to load shape inputs—Fall weekend, 1989. (XBL 8612-5016)

Detailed calibration tests were conducted for three representative years over the simulation period. Annual energy production for each resource type was compared as well as the annual value for marginal energy cost calculated by LMSTM and the detailed model. Production by fuel type was within 2% for baseload resources. For marginal resources the deviations were large, averaging 15%. The results for annual energy marginal cost, however, were better. The average deviation was 5%. These results are sufficiently close for use in strategic planning studies of the type envisioned. They are substantial improvements over previous efforts of this kind, due largely to more accurate specification of system constraints.

## PLANNED ACTIVITIES FOR FY 1987

In FY 1987, LBL will use the calibrated model to evaluate future expansion plans based on large-scale implementation of demand-side programs. These programs will emphasize thermal energy storage applications and improved efficiency of residential appliances and commercial building equipment. The value of such programs will be estimated by calculating the amount of supply-side resources that can be eliminated by implementing them.

## SUGGESTED READING


1. Kahn, E., Pignone, C., and Comnes, A. (1986), *LMSTM Calibration for Least Cost Planning*, LBL-22702.
2. Kahn, E. (1986), *Proxy Plant Valuation Methods for Demand Side Utility Programs*, LBL-21525.

# INTERNATIONAL ENERGY STUDIES

## Overview

The International Energy Studies (IES) Group has been involved in research on energy demand since 1979. The work of the IES Group focuses on two areas: (1) energy demand in the industrialized countries; and (2) energy demand in the developing countries. The research on industrialized countries primarily addresses energy use in buildings, though work on the industrial sector is also underway. The research on the developing countries looks at demand in all sectors and also examines issues of energy supply.

The guiding philosophy of the Group is that understanding the evolution of energy demand requires careful examination of the structural forces that shape demand for energy, as well as the economic parameters. We seek to relate changes in energy demand to changes in the physical setting for energy use, looking in particular at changes in the efficiency of each energy end-use. We use comparisons of different countries to establish a context for understanding the observed patterns and for assessing trends in energy consumption.

The IES Group, which consists of scientists of different disciplinary backgrounds, is international in composition and multi-lingual. Visiting researchers from many different countries have been and are active participants in IES projects. The Group's work is a major activity in the Energy Analysis Program at LBL.

### ENERGY DEMAND IN DEVELOPING COUNTRIES

Since its beginnings in this area with a study of energy use and conservation in Kenya's modern economy, the IES Group has expanded its research into energy demand in developing countries in four continents. In work funded by the U.S. Department of Energy and by several major energy companies, we have examined trends in energy use and structural change in 20 major energy-consuming developing countries in Asia, Africa, Latin America, and the Middle East, which together account for about 80% of developing countries' energy consumption.

The goal of our work is to understand how energy demand has changed in response to (often) rapid economic growth and two oil shocks. We examine how changes in economic structure, energy-use efficiency, and fuel mix will change demands in the future. A particular focus is the extent to which the growing demand for oil in the oil-exporting developing countries would reduce the amount of oil exported. The reduced exports combined with the declining production of oil in the U.S. would increase reliance on oil from the Middle East.

In addition to research on energy demand, the Group has also been involved in a number of evaluations of energy supply options for particular developing countries. A new area of work is assisting the U.S. Agency for International Development in developing effective programs to encourage expanded deployment of economically viable renewable energy options, and to better manage the use of electricity in developing countries.

### ENERGY DEMAND IN THE INDUSTRIALIZED COUNTRIES

The Group's research on energy demand in the industrialized countries provides consistent information on energy demand in many of the world's largest energy-consuming countries as well as a context to better understand changes in U.S. energy consumption. Beginning with a comparison between the U.S. and Sweden, the research has evolved to include 9 European countries as well as Japan, the U.S., and Canada.

We developed the first and only data base of residential energy use in industrialized countries, now used as a reference by the International Energy Agency, energy authorities in many countries, and major oil companies. We have published several overviews of industrialized countries' residential energy use, and separate studies of individual countries focusing on the reversibility of oil use and structural change in electricity demand.

Additionally, we have expanded the work to include the service and industrial sectors. Current work on the residential sector includes analysis of the evolution of gas demand in Europe, development of scenarios of future energy demand, and investigation into the impacts of lifestyle changes on future household energy use.

# Residential Energy Demand In Selected OECD Countries: Historic Trends and Future Directions*

*A. Ketoff, S. Bartlett, D. Hawk, S. Meyers and L. Shipper*

In the first stage of this project we compiled historical data on residential energy use for eleven Organization for Economic Cooperation and Development (OECD) countries—Canada, Denmark, France, Germany, Holland, Italy, Japan, Norway, Sweden the United Kingdom, and the United States—from 1970 to 1984. We present detailed statistics on energy consumption as well as on related economic and structural activity. In addition, graphical presentations have been included to support the data found in the tables.[1]

From the above work, we have selected the six largest OECD countries—France, Germany, Italy, Japan, the United Kingdom, and the United States—and have written a comprehensive analysis of historical trends in residential energy demand from 1973 to 1984. The focus of this report is on how and why the demand for different fuels—oil, gas, solids, and electricity—has been changing overall energy demand. For each major end use (space heating, water heating, cooking, and electric appliances), we examine the changes in the consumption for each fuel. Structural elements are the characteristics of the residential buildings and the energy-using equipment in them. Some of the structural changes have pushed upward on energy consumption, and others have pushed downwards. We also consider behavioral changes, i.e., the way people use the energy-using equipment.

We will examine the future directions of residential energy demand.

## ACCOMPLISHMENTS DURING FY 1986

Energy consumption in the residential sector has undergone considerable change in the period since 1973. Final energy consumption has declined or grown moderately in all of the countries (except Japan where average growth was 2.4% per year between 1973 and 1984). This occurred despite a growth in the number of households of between 1 and 2% per year during the 1973-83 period. Average final energy consumption per home declined the most in the U.S. and France. The decline in unit consumption was the result of many competing forces. In the early 1970s, an increase in the penetration of central heating, various appliances, and the growth in the number of households pushed upwards on energy consumption. In the late 1970s and the early 1980s, several trends emerged to counteract these forces: lowering of indoor temperatures, increased thermal performance of existing homes, improved thermal performance of new homes, and the increased efficiency of new electric appliances. In addition, the growth in the structural energy intensity was slowing.

In the early 1970s, the introduction of central heating systems in Europe caused coal-based heating systems to be replaced by other fuels, mainly by natural gas. This occurred in the United States in the 1960s. After the 1973 oil price shock, natural gas and electricity displaced oil in the market of new heating systems. When energy prices experienced a second major increase in 1979 and 1980, fuel switching (from oil to gas and electricity) was accelerated.

By 1984, with real oil prices stabilizing, the stock of houses and the saturation of fuels in them was very different from the condition of 1973. The structure in European countries was closer to the United States than was the case in 1970.

## PLANNED ACTIVITIES FOR FY 1987

We plan to develop projections of future residential demand for each fuel for 1990 and 2000. The basic method involves estimating the number of homes and the intensity of use by fuel for each end use. We will base our estimates on the historical evolution of the above variables and the factors that determine them, including the individual country's policies towards the promotion of each fuel.

## REFERENCES

1. Ketoff, A., Bartlett, S., Hawk, D., Meyers, S., and Shipper, L. (1986), *Evolution of Residential Energy Demand in OECD Countries, Part One: 1970-1984 Data Base,* LBL-22267.

*This work was supported by the Assistant Secretary for Conservation and Renewable Energy, Office of Buildings and Community Systems, and by the Assistant Secretary for Defense Programs, Office of the Deputy Assistant Secretary for Intelligence, of the U.S. Department of Energy, under Contract No. DE-AC03-76SF00098.

# Changing Patterns of Electricity Demand in Residences*

*L. Schipper, A. Ketoff, S. Meyers, and D. Hawk*

## ACCOMPLISHMENTS DURING FY 1986

This report explores the major factors that shaped household electricity demand in the U.S. and ten other Organisation for Economic Cooperation and Development (OECD) countries from 1960 to 1983. We explain the differences among countries in addition to analyzing changes in each country over time. Also, we identify important trends abroad that may have implications for the use of electricity in American homes. It is structured around a "bottom-up analysis" that decomposes electricity demand into components representing structure and unit consumption for all major uses in homes.

Demand for electricity grew between 2.9% (U.S.) and 9.4% (France) per year during the period from 1972/3 to 1983. Only in the U.K. did electricity consumption decline over this period and at a rate of less than 1% per year. Prior to 1973, electricity consumption increased due to growing appliance saturation in most countries. In response to the dramatic oil price increases in 1973, new homes were equipped with electric space and water heaters instead of oil-fired equipment. In addition, some homeowners converted from oil-fired to electric space and water heating. These two trends account for most of the growth in electricity use in the mid-1970's. From 1979 through 1983, demand in many countries began to stagnate or even fall. This was the result of several competing trends. The market for many appliances had become saturated and the impact of more efficient electric appliances became appreciable by the early 1980's. Similarly, the building shells of new homes built for electric heating became increasingly tighter, reducing the average consumption for heating. Higher electricity prices also induced conservation by families using electricity for hot water, heating, cooking, and lighting. Demand would have declined more dramatically if the electric space heating market hadn't significantly expanded during this period.

Average growth in residential electricity demand over the past twenty years has been higher in Europe and Japan than in the United States. This is because the penetration of appliances and electric space and water heating equipment was significantly higher in the U.S. at the beginning of the period.

In the future, electricity is likely to increase its penetration in each end-use market, but each use will continue to become more efficient. Increased efficiency may encourage greater electricity penetration, perhaps balancing the downward effect of increased efficiency on total sales.

The main potential growth areas for residential electricity use are space heating, water heating, and three major appliances whose saturations are still under 50% in most countries: freezers, dishwashers, and clothes dryers. Space heating remains the major unsaturated market, particularly in the U.S., France, and Japan. Although electric heat enjoys an important role in new construction in these countries, the housing turnover rate is slow. In the long run, construction of homes with thermally efficient shells and the trend toward more multiple family dwellings are factors that seem to favor use of electric space heating. New uses such as computers and VCRs are likely to play a minor role in increasing electricity use in the future because they require little energy to function.

## PLANNED ACTIVITIES FOR FY 1987

We will continue to study residential electricity demand and consumption in OECD countries in FY 1987.

## SUGGESTED READING

1. Schipper, L., Ketoff, A., Meyers, S., and Hawk, D. (1986), *Electricity and The Home: An International Overview of Trends*, LBL-21187.

*This work was supported by the Assistant Secretary for Conservation and Renewable Energy, Office of Buildings Energy Research and Development, Building Systems Division of the U.S. Department of Energy, under Contract No. DE-AC03-76SF00098, and by the Electric Power Research Institute.

# Residential Natural Gas Demand in Western Europe*

*A. Ketoff, S. Bartlett and O. Olsen*†

This project examines the evolution of natural gas demand in the residential sector in seven Western European countries from 1970 to 1984. The countries studied are Denmark, France, Germany, Holland, Italy, Sweden, and the United Kingdom. The analysis focuses on trends in the following determinants: consumption, the structure of the dwelling stock, and the intensity of use. Trends for each major end-use (heating, water heating, and cooking) are examined. Changes within each country and the differences among countries over that time period are explored.

## ACCOMPLISHMENTS DURING FY 1986

From 1970 to 1984, the demand of natural gas grew at an annual average rate of 8.7% for the seven countries. Among the countries, growth has varied from 7 to 13% in France, Germany, Italy and the U.K. Growth was lower in Holland, where the market was already saturated, and in Denmark and Sweden, where natural gas represents only a small fraction of total energy demand. In each country (with the exception of Denmark and Sweden) the share of natural gas as a fraction of total fuels used has increased substantially. (See Fig 1.) Conversions from oil-based to gas-based heating have been significant in five countries (France, Germany, Holland, Italy, and the U.K.). In addition, the share of new homes that use natural gas in these five countries has increased dramatically. The study reveals that the intensity of gas systems decreased considerably since the early 1970's, even though the increased penetration of central heating systems has somewhat offset this trend. In the future, the intensity of natural gas use within the home will be limited by the saturation of gas central heating, and the effects of improved system efficiency and better insulation, but more homes will use natural gas, thus increasing demand.

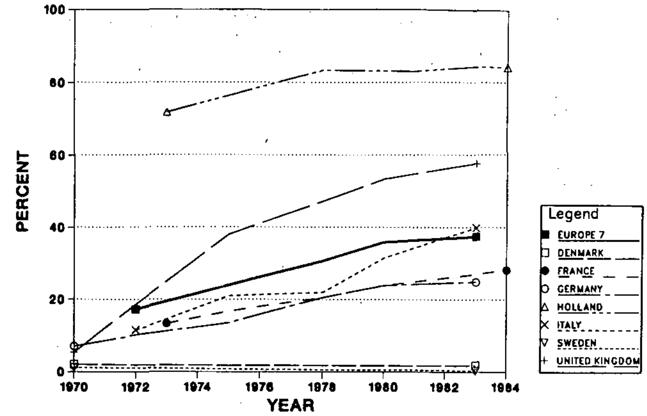



**Figure 1.** Natural gas share of residential energy use in Western European countries. (XBL 871-6)

This work relates to the development of a discrete-continuous dynamic-choice model, undertaken during FY 1985-1986, and preliminary runs of the model have been successfully completed.

## PLANNED ACTIVITIES FOR FY 1987

The project will be expanded to include projections of future natural gas demand within each country.

## SUGGESTED READING

1. Dagsvik, J., Lorentsen, L., Olsen, O., and Strom, S. (1986), *Residential Demand for Natural Gas: A Dynamic, Discrete-Continuous Choice Approach*, presented at the IAEE Eighth Annual International Conference, Tokyo, Japan, North Holland Press (to be published).

*This work was supported by the Assistant Secretary for Conservation and Renewable Energy, Office of Buildings and Community Systems, and by the Assistant Secretary for Defense Programs, Office of the Deputy Assistant Secretary for Intelligence, of the U.S. Department of Energy, under Contract No. DE-AC03-76SF00098.

† Oystein Olsen is a visiting research fellow at LBL from the Central Bureau of Statistics, Oslo, Norway.

# Energy Consumption and Structure of the U.S. Residential Sector: 1986 Update*

*S. Meyers*

Investigation of energy consumption by the U.S. residential sector has been part of the international research on residential energy use by the International Energy Studies Group for several years. The basis of our approach is the belief that changes in energy consumption must be looked at in the context of changes in the structural setting for that consumption.

## ACCOMPLISHMENTS DURING FY 1986

In FY 1985, we began to put together a comprehensive overview of the trends in U.S. residential energy consumption in the 1970-1984 period and the chief structural factors shaping those trends.[1] In FY 1986, we completed this work and extended it to include energy consumption data for 1985 and data on household behavior from the 1984 Residential Energy Consumption Survey (RECS).

Residential final energy consumption, adjusted to normal climate, increased in 1984, but then fell slightly in 1985 (see Table 1). The main reason for this decrease in 1985 was decline in consumption of natural gas. Oil consumption grew by about 6% in 1985, a response to lower prices, and electricity demand increased modestly.

Energy consumption per household declined in 1985 after having increased in 1984. The level in 1985 was about the same as in 1983. It could be that the "down-up-down" pattern of demand in the 1983-85 period, which is a result of reported changes in natural gas consumption, is in part due to problems with the statistics.

Consumption of natural gas per customer in 1985 was 11% below the level of 1980. This indicator declined to a new low in 1985 after having risen in 1984. Consumption of oil per customer (not including apartments) was stable in the 1983-85 period, but did not rise above the level of 1982/83. Consumption of electricity per customer was slightly higher in 1984 and 1985 than in 1983.

*This work was supported by the Assistant Secretary for Conservation and Renewable Energy, Office of Buildings Energy Research and Development, Buildings Equipment Division of the U.S. Department of Energy, under Contract No. DE-AC03-76SF00098.

**Table 1.** U.S. residential energy consumption, adjusted to approximate normal weather[a] (quadrillion Btu).

| | Gas | Oil | Elec. | Wood | Total Final[b] | Final per HH[c] |
|---|---|---|---|---|---|---|
| 1980 | 4.82 | 1.58 | 2.43 | 0.86 | 9.65 | 119 |
| 1981 | 4.77 | 1.43 | 2.51 | 0.87 | 9.53 | 116 |
| 1982 | 4.75 | 1.35 | 2.52 | 0.94 | 9.47 | 113 |
| 1983 | 4.52 | 1.23 | 2.54 | 0.93 | 9.19 | 110 |
| 1984 | 4.76 | 1.25 | 2.67 | 0.98 | 9.63 | 113 |
| 1985 | 4.52 | 1.33 | 2.71 | 0.90 | 9.46 | 109 |

[a]Total includes LPG and coal.
[b]Excludes 50% of wood consumption to account for low efficiency of use.
[c]Million Btu.

The sharp drop in energy consumption in 1980 and the continued decline through 1983 reflect the upsurge in retrofit activity in 1979-80 and lowering of indoor temperatures. Retrofit activity slowed in 1981 and slowed further in 1982, but was by no means negligible. The decline and stagnation of disposable income in the 1980-82 period probably acted to inhibit household spending on retrofit. The 1984 RECS indicates that the level of retrofit activity in 1984 was higher than in 1982; this suggests that households were still investing in conservation even though energy prices had stabilized.

The combination of the recession and considerable growth in the price of natural gas, electricity, and (through 1981) oil was strong encouragement for a "belt-tightening" response on the part of households in the early 1980s. It appears that winter indoor temperatures crept upward in 1982, but the 1984 RECS indicates that there was little change between 1982 and 1984. Given the growth in income and stabilizing of natural gas prices, this is somewhat surprising, and suggests that households may have become comfortable with the heating habits developed over the past decade.

## PLANNED ACTIVITIES FOR FY 1987

In FY 1987, we will incorporate results on energy consumption from the 1984 RECS into our analysis.

## REFERENCES

1. Meyers, S. (1986), *Energy Consumption and Structure of the U.S. Residential Sector: Changes Between 1970 and 1984,* LBL-21190.

# Energy Demand in Asian Developing Countries*

*J. Sathaye and S. Meyers*

Energy demand in the developing countries of Asia grew faster between 1973 and 1983 than in any other region except Africa. To better understand the future direction of this demand and the mix of fuels, we studied energy use by sector in 10 Asian countries: Bangladesh, China, India, Indonesia, S. Korea, Malaysia, Pakistan, the Philippines, Taiwan, and Thailand. Together, these countries account for over 90% of energy consumption in Asian developing countries. China, with 45% of the combined population, dominates the regional picture when it is included.

## ACCOMPLISHMENTS DURING FY 1986

Total energy demand of the study countries grew at an average of 5.8% per year between 1973 and 1983 while oil demand averaged 5.4% per year. Demand for coal grew at a similar rate, though growth was much higher in some countries. Natural gas use grew fastest, though it remains relatively insignificant in the overall picture.

Energy consumption per capita grew at an average rate of 3.8% per year between 1973 and 1983. For oil consumption per capita, all of the growth came before 1980; consumption per capita rose in 1983 but was still below the 1979 peak. The fastest growth occurred in Indonesia, S. Korea, and Malaysia. Only in the Philippines was there negative growth. Energy consumption per unit of GDP (in 1980 US $) was about the same in 1983 as it was in 1973. It rose somewhat between 1974 and 1979, and then fell through 1982. Oil/GDP shows a similar trend as energy, though with a bit more decline. The oil/GDP ratio was much higher in 1983 than in 1973 in Indonesia and Pakistan, slightly higher in India and Malaysia, and was lower in the other countries.

Industrial energy consumption per unit of value added was slightly higher in 1983 than in 1978. Oil intensity in 1983 was 19% below its 1979 level. Oil intensity declined in all countries except Indonesia and Pakistan. In Bangladesh, Korea, the Philippines, and Thailand, the decline was very large. Substitution of coal and natural gas for oil was the primary cause of the decline in oil intensity. Energy conservation efforts and the introduction of new, more energy-efficient equipment had a strong effect in the Philippines, Korea, and Thailand.

Gasoline and diesel consumption per motor vehicle declined by 30% from 1978 to 1983. Growth in the share of motorcycles in the vehicle stock played a major part in the decline in intensity. The number of motorcycles increased at an average rate of 15% annually, while that of cars and pickup trucks increased at a rate of 9.1%. Higher fuel prices led to less use of vehicles, and the average operating efficiency of cars improved in most countries.

Residential/commercial energy consumption per capita was about 16% higher in 1983 than in 1978, though there was little growth in 1982 and 1983. Oil intensity grew in Korea, India, Malaysia, and Taiwan, but declined substantially in Bangladesh, the Philippines, and Pakistan. Increased use of oil for cooking and growing penetration of electric appliances are the main forces behind the growth in energy intensity.

In the power sector, oil consumption per kWh generated declined by 25% in the 1978-83 period as coal, natural gas, and other sources came into greater use. The largest declines were in Taiwan and Thailand. There was also considerable decline in Korea, Bangladesh, and Malaysia.

Lower oil prices may slow the move away from oil and accelerate demand, depending on the extent to which they are passed on to consumers. Our estimates show final energy demand for the nine countries (excluding China) increasing at an average annual rate of 4.1-5.9% between 1983 and 2000, and oil demand growing at 3.5-6.2%. Final energy demand per capita increases from 0.14 to 0.20-0.28 TOE.

## PLANNED ACTIVITIES FOR FY 1987

We will incorporate more recent data from the Asian study countries and will assess changes that are occurring as a result of the decline in oil prices. For several countries, we will study in detail the direction of transportation energy demand.

*This work was supported in part by the Office of Policy, Planning, and Analysis, of the U.S. Department of Energy under Contract No. DE-AC03-76SF00098, and in part by grants from British Petroleum, Chevron, CONOCO, Exxon Corporation, Shell International Petroleum Company, Shell USA, and Statoil.

# Energy Demand in Latin America*

*A. Ghirardi*

Energy demand in Latin America accounts for around 40% of total energy use in the Less Developed Countries (LDCs). In order to better understand the future direction of this demand and the mix of fuels, we studied energy use by sector in four countries: Argentina, Brazil, Mexico, and Venezuela. Together, these countries account for around 75% of energy consumption in Latin America.

## ACCOMPLISHMENTS DURING FY 1986

Patterns of energy demand in Latin America have been substantially affected by the increases in energy prices and the availability of fossil fuel reserves. There was a distinct decline of petroleum intensity in the post-1979 period due mostly to conservation and substitution measures, especially in Argentina and Brazil. The share of petroleum in primary energy supply fell from 60% in 1970 to 49% in 1984, while the shares of natural gas and hydroelectricity increased from 23 to 25% and from 14 to 22%.

Per capita energy use in the four-country aggregate increased by around 70% from 1970 to 1980, and remained stable thereafter. Oil intensity peaked in 1980, then fell through 1984. Most of the reduction in petroleum intensity took place in the Argentinian and Brazilian industrial and transportation sectors. Significant reductions also occurred in power generation in Argentina and Venezuela.

In industry, energy intensity increased, especially after the mid-1970s, as a result of the expansion of energy-intensive activities. Energy use per unit of industrial value added increased by 30%. Industrial oil intensity increased up to the mid-1970s, and then declined by 33% between 1978 and 1983. The biggest reductions were achieved in Argentina (through substitution with natural gas), and Brazil (by imposing quotas on fuel oil use, and providing subsidies for coal and electricity as alternative fuels).

Gasoline plus diesel use per vehicle fell by 50% from 1970 to 1984. The decline was largest in Brazil, due to the substitution of ethanol for gasoline, and smallest in Venezuela, where prices remain much below those of the other countries.

The residential/commercial sector is the only one where energy intensity increased in all countries, nearly doubling in the period 1970-84. The oil intensity also increased steadily due in part to pricing policies that protected residential users from the oil price increases.

In power generation, there was strong substitution away from fuel oil and towards hydropower and natural gas. Oil use per GWh generated fell by 30% from 1970 to 1984. There is evidence that the declining price of petroleum and surpluses of fuel oil are having an impact, as hydro projects have been delayed in Argentina and Venezuela. Coal and nuclear power should continue to play a relatively small role in electricity generation.

The future demand of petroleum fuels is an issue for both oil exporters and importers. For the exporters, oil is the main source of foreign exchange. With low oil prices, Mexico and Venezuela need large increases in exports to maintain the necessary inflow of foreign exchange. This could provide incentive for the formulation of policies fostering conservation and substitution in their domestic markets.

For the oil importers, the decline in petroleum intensity observed in 1979-83 may have bottomed-out. Given the substantial decline in the price of petroleum, they have much less incentive to continue reducing their oil intensity. Particularly vulnerable are the substitution programs based on heavy price subsidies to alternative fuels, as in the case of electricity and coal in Brazil. Even where there are substantial natural gas reserves, it may be more attractive to reduce natural gas production and use some of the growing fuel oil surplus.

## PLANNED ACTIVITIES FOR FY 1987

We will incorporate more recent data from the study countries and will assess changes that are occurring as a result of the decline in oil prices. For several countries, we will study in detail the direction of transportation energy demand.

## SUGGESTED READING

1. Ghirardi, A. (1986), *Dynamics of Change in Oil and Energy Use in Four Latin-American Countries*, LBL-22788.

*This work was supported in part by the Assistant Secretary for International Affairs and Energy Emergencies, Office of International Energy Analysis, of the U.S. Department of Energy, under Contract No. DE-AC03-76SF00098, and in part by grants from British Petroleum, Chevron, CONOCO, Exxon Corporation, Shell International Petroleum Company, Shell USA, and Statoil of Norway.

# Energy Demand in West Africa*

*A. Ghirardi, J. Sathaye, and P. Goering*

This article reports on an overview of the energy market in four West African countries: The Ivory Coast, Morocco, Nigeria, and Senegal.[1] Together they account for 75% of the total energy use in West Africa, 78% of Gross Domestic Product (GDP), and 76% of population. The purpose of the study is to analyze the evolution of energy demand in the context of the general socio-economic background of the region. The study also examines energy supply, and trade related to the energy sector. The analysis focuses on the study of commercial fuels.

The work on demand draws on the energy and economic data prepared for the Developing Country Data Series, developed by the International Energy Studies Group (IES). The data and relevant information were obtained from local sources during visits to each of the four countries surveyed. We contacted government offices (ministries and statistical bureaus), academic research institutions, and private companies (oil refineries and distributors, electric utility companies). The work on supply is based on a literature review done by IES[2] as well as on information from our country contacts.

## ACCOMPLISHMENTS DURING FY 1986

The commercial energy market in the four West-African countries surveyed has two salient characteristics: a) it is among the fastest growing in the world; b) it is driven primarily by the demographic explosion in urban centers.

Throughout the 1970s and early 1980s, the growth of energy demand in the region has been fast and nearly continuous. The aggregate energy use more than doubled from 1974 to 1983, increasing at an average annual rate of 10%. During the same period, energy use per capita grew at an average 5%. Although all countries of the group showed substantial growth potential, the most dramatic increase in energy demand occurred in Nigeria, reflecting the abundance of domestic petroleum supply, and the relatively low prices of petroleum products. At current growth rates, the average per capita energy use in West Africa will have doubled by the turn of the century.

Energy resources in the region are adequate, although unevenly distributed and developed. Although all the countries have refineries, capacity is not well adapted to the domestic markets. Demand for middle distillates will continue to be higher than can be satisfied internally. Nigeria especially has to import middle distillates.

Trade in the region will be hampered by the large foreign debt of all the countries and by balance of trade deficits. Morocco and Senegal in particular are saddled with huge debts and economic recovery in these countries will be a long slow process. The future policies of Nigeria will depend on the international oil market and on internal politics. International aid may be the only source of much needed capital for energy sector improvements in the majority of countries.

## PLANNED ACTIVITIES FOR FY 1987

We will continue to update and expand on our work in this area in FY 1987.

## REFERENCES

1. Ghirardi, A., Sathaye, J., and Goering, P. (1986), *Energy Assessment of Ivory Coast, Morocco, Nigeria, and Senegal*, LBL-22586.
2. Kahane, A., and Lawakabamba, S. (1985), *Energy in West Africa: A Literature Survey*, IES/LBL, Report to the Energy Research Group, International Development and Research Centre, Canada.

This work was supported in part by the Assistant Secretary for International Affairs and Energy Emergencies, Office of International Energy Analysis, U.S. Department of Energy under Contract No. DE-AC03-76SF00098, and in part by grants from British Petroleum, Chevron, CONOCO, Exxon Corporation, Shell International Petroleum Company, Shell USA, and Statoil of Norway.

# Mexico Oil Balance and Opportunities for Conservation*

*A. Ketoff*

Mexico's abundant oil reserves spurred the development of a highly oil-intensive domestic economy. While oil demand continues to grow despite the recession of the last four years, the recent drop in oil prices—and therefore in export revenues—is limiting the country's capacity to invest in new exploration. At the same time, the country's need to generate foreign exchange to pay its debt service may force an escalation in oil exports. A conflict is emerging between Mexico's need to satisfy the domestic demand for oil and its need to export oil to service the debt. In this context, an oil conservation policy appears to be the only viable alternative, although its potential will be limited by lack of capital.

## ACCOMPLISHMENTS DURING FY 1986

The sectoral analysis presented in our report identifies unexplored opportunities for energy conservation and points to the forces that will drive future patterns of demand.[1] Unlike the other Latin American countries we have studied, where major drops in the intensities occurred in the seventies, overall energy and oil intensity in Mexico's industrial sector varied only slightly between 1970 and 1981. Also, unlike Brazil or Venezuela, no substantial electrification of the industrial production took place, except for steel. This is partially explained by the fact that the most electric-intensive industrial process, aluminum production, has not been developed in Mexico.

By conducting a sectoral analysis of the most oil-intensive economic sectors, we have identified the oil sector and the electricity sector as having large savings potential. Significant savings can be achieved in both sectors through the adoption of cogeneration methods in the transformation process. By reducing electricity consumption in the production of paper, chemicals, and steel, such measures could also generate substantial savings in oil consumption.

While the recession forced a 50% decrease in real wages, forcing marked reductions in the demand for cars, housing, and appliances, and thus reducing oil consumption in the transportation and residential sectors, demand growth is expected to resume in both sectors although at a lower pace. To prevent a re-emergence of the wasteful patterns that characterized the expansion period, it is important that efforts be made to channel demand in these sectors to energy efficient products.

The prolonged recession has prevented Mexico from investing in exploration and production activities, freezing production capacities at 1982 levels. At the same time, lack of investment in all industrial sectors prohibited the emergence of any new and vigorous industry capable of complementing the oil sector's export potential. With the current drop in international oil prices, the conservation actions identified here appear to be the only alternative to more severe measures limiting the recovery potential of the country.

## PLANNED ACTIVITIES FOR FY 1987

Mexico supplied over 700 thousand barrels a day of oil to the U.S. in 1986. Its importance will increase in the future as the U.S. dependence on oil from the Middle Eastern countries rises. Mexico's internal demand for oil will then pose a major obstacle in U.S. attempts to import a larger share of oil from that country. During FY 1987, we plan to analyze the potential for curbing the internal demand for oil in Mexico and its implications for reducing the U.S. vulnerability to disruptions in oil supply.

## REFERENCES

1. Ketoff, A., and Schiorring, E. (1986), *Mexico Oil Balance and Opportunities for Conservation*, LBL-21186.

This work was supported in part by the Assistant Secretary for International Affairs and Energy Emergencies, Office of International Energy Analysis, U.S. Department of Energy under Contract No. DE-AC03-76SF00098, and in part by grants from British Petroleum, Chevron, CONOCO, Exxon Corporation, Shell International Petroleum Company, Shell USA, and Statoil of Norway.

# Renewable Energy Sources in Less Developed Countries*

*J. A. Sathaye*

In November 1984, the Agency for International Development (AID) Administrator called for a critical assessment of AID's renewable energy activities. He outlined the objectives of the assessments as:

1. To assess priority applications of renewable energy technologies, with emphasis on productive uses in agriculture and rural industry.
2. To recommend development and application of those renewable systems which, when compared with alternatives, are the least-cost, site-specific solutions for supplying energy needs.
3. To suggest means of developing local private sector capability to market, manufacture, and maintain the most promising energy systems and to involve the private sector at an early stage in AID projects.

## ACCOMPLISHMENTS DURING FY 1986

Responding to the above objectives, AID initiated a new Renewable Energy Applications and Training Project (REAT). An interim report was to be prepared for the Administrator in FY 1986 and a final report in FY 1987. LBL collaborated with Oak Ridge National Laboratory in the preparation of this interim report during FY 1986. The findings of this report are summarized below.

A decade ago, renewable energy sources—solar energy, biomass, and small hydropower, among others—seemed the solution to many energy problems for developing countries. These resources offered ways to use indigenous energy supplies in place of expensive imported oil at scales appropriate to local needs as part of a world-wide movement to replace shrinking fossil fuels with sustainable sources of energy.

Many technologies, still experimental in the mid-1970s, have been shown to perform reliably. However, many problems resulted in the rush to exploit new and renewable energy sources. Some technologies were widely promoted in developing countries prior even to their adoption in the developed countries. The lack of experience of technology developers resulted in unsuccessful projects in the unfamiliar physical and social environment and often harsher political climate. Matching technologies to end-uses and understanding the priorities of users, two factors central to the success of renewable projects were often ignored in the haste to design and implement projects. In recognition of this experience, the reassessment of renewables will help clarify lessons learned and establish new directions for AID to follow.

The initial findings of the reassessment are that certain renewable energy options, including hydropower, solar photovoltaics in specific uses, direct combustion of biomass, and wind for mechanical power are proven technically and economically viable. Projects were most successful when they incorporated potential local manufacturers and users in design and application, stressed commercial viability via economic competitiveness with alternatives, and used proven technology. Decentralized hydro-power, biomass energy for power and non-power purposes, and photovoltaics in specialized uses, all can effectively support rural development, reduce energy costs and effectively meet energy needs of the rural poor. Good project design and execution, including prior evaluation of needs, adaptation to the local economic, social and geographic circumstances; and favorable government policy, are as important as soundness of technology.

## PLANNED ACTIVITIES FOR FY 1987

The final report, to be completed in FY 1987, will refine and expand the lessons learned. Further examples will be presented and supported with detailed analyses. The report will recommend strategies for AID decision-making. These may include guidelines for determining needs which might benefit from energy sector interventions and for evaluating alternatives, an initial set of country and regional energy sector projects which complement mission and country development strategy, and guidelines for AID missions regarding renewable energy project management.

*This work was supported by Oak Ridge National Laboratory, through the U.S. Department of Energy, under Contract No. DE-AC03-76SF00098.

# RESOURCE MARKET MECHANISMS

## Overview

The Resource Market Mechanisms group analyzes and conducts research on the methods used for the transfer of natural resources, particularly the transfer, by means of formal competitive auctions, from government to the private sector as well as on broader energy policy issues.

The following article contains a description of an analysis of the use of negotiations instead of auctions for the sale by the federal government of "captive" coal tracts. In the recent past, there have been studies of federal lumber auction formats, of issues in oil leasing, and of the use of auctions by the State of California. There has also been modelling in support of natural gas deregulation policy analysis.

We are currently undertaking a study to evaluate alternative ways for electric utilities to conduct auctions for the purchase of cogeneration power. This study is also considering the issues that would arise if broadening cogeneration auctions to include any new source of power generation was used as a means of deregulating power generation. There is also underway a theoretical analysis of auctions with withdrawable bids. In addition, as part of a program of studies in support of the analysis of energy emergency policies, we are undertaking a reassessment of U.S. energy vulnerability in the 1990's.

## Analysis of Options for Coal-Lease Sale Negotiations*

*M.H. Rothkopf and C.B. McGuire*[†]

The Commission on Fair Market Value Policy for Federal Coal Leasing recommended that the government have authority to negotiate a fair price for coal leases when competitive bids cannot be obtained.

### ACCOMPLISHMENTS DURING FY 1986

In FY 1986, we completed a report that analyzes the choices the government faces in designing a coal lease sale mechanism. It considers the impact of the alternatives on economic efficiency, government revenue, administrative workability, fairness and the appearance of fairness.

The report concludes that there are advantageous ways for the government to negotiate coal leases when there is only one serious potential bidder for a lease. First, the report notes the advantages of negotiating exchanges that leave the government with economically logical potentially minable tracts. It also notes the advantages of negotiating shares for the "cooperative leasing" by auction of such tracts.

For other one bidder tracts, the report concludes that there are potential advantages to lease negotiation provided that:

1) all negotiations are tentative subject to "validation" of their one bidder nature in a post-negotiation formal sale process,
2) the government negotiate on more leases than it will conclude, using whenever possible, a "round-robin" negotiation procedure,
3) government employees and not independent agents negotiate for the government, and
4) negotiations are narrowly confined to the amount of bonus.

The report also suggests that the government may wish to consider use of final-offer arbitration on those leases, such as bypasses, on which both the government and the private party have high interest in reaching an agreement. Figure 1 illustrates a potential decision sequence developed in the report.

*This work was supported by the U.S. Department of Interior, Bureau of Land Management, under contracts with Dames and Moore and the U.S. Department of Energy, under Contract No. DE-AC03-76SF00098.

† Affiliated Faculty, LBL, and Professor, Graduate School of Public Policy, University of California, Berkeley.

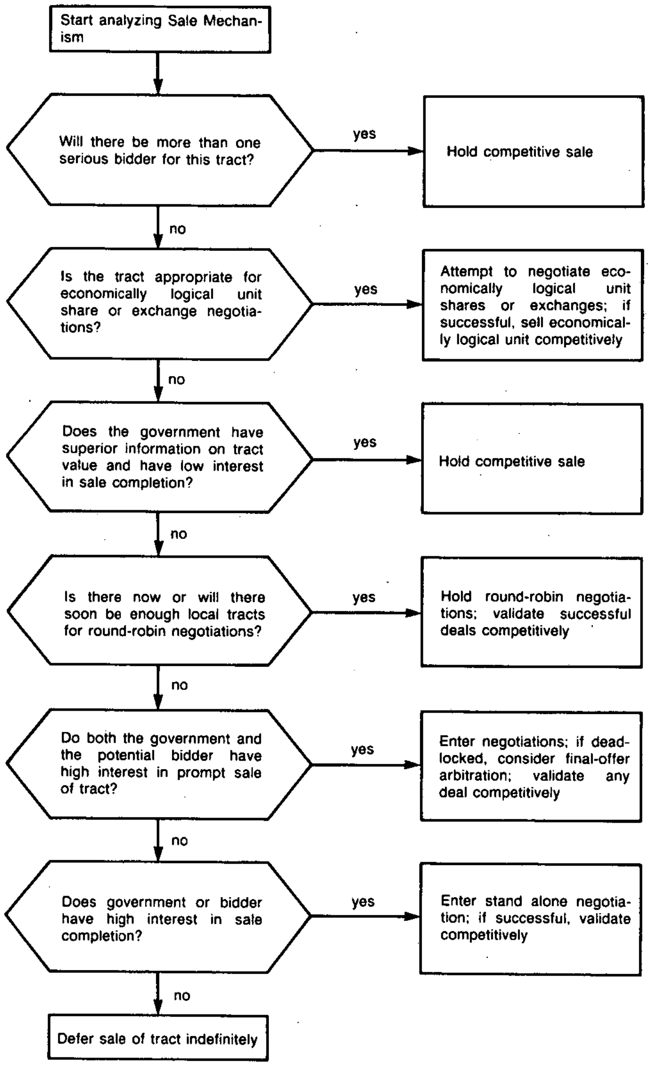



**Figure 1.** Potential decision sequence for selecting a sale mechanism for a coal tract (XBL-8611-9695)

The report identifies several issues worthy of further study.

The government, in arranging coal leases, has several different and sometimes conflicting objectives. The government wants to promote economic efficiency. In particular, it wants to lease the coal that is most economic to develop to the party and under the terms that will lead to its most efficient development. Within the range of prices that could be considered a fair market value, the government would prefer to collect more rather than less revenue in return for its asset. The government would like the leasing system to be fair to all interested parties and to avoid it even appearing unfair. Finally, the government is concerned that the leasing process itself be inexpensive and administratively workable. For these reasons, we examine various approaches to negotiating coal leases and conditions under which they might outperform auctions with respect to some or all of these criteria.

Overall, we conclude that it is to the government's advantage that:

- coal lease negotiations be considered in apparent one bidder situations only,
- the Bureau of Land Management (BLM) encourage exchanges that will give it an economically logical potential mine that can then be sold competitively,
- the BLM negotiate shares of economically logical potential mine that can then be sold competitively,
- if the BLM has unusually precise knowledge of the fair market value of a tract, and a relatively low interest in sale completion, it offer the tract for lease competitively,
- all negotiations of coal leases be tentative, subject to a post-negotiation formal sale, and that in such sales, the negotiated terms be known and the company with which they were negotiated be barred from improving them,
- when several captive tracts in an area are available to be leased within a reasonable time period, the BLM use some form of round-robin negotiations and lease only some of them,
- when both parties have a high interest in the sale of a lease, the BLM negotiate and consider resort to final-offer arbitration,
- in all other captive tract situations, if the BLM is prepared to negotiate, it do so with the expectation that a substantial percentage of negotiations will fail,
- the BLM use employees and not agents to negotiate, and
- the BLM use negotiation fees only if it can be sure no moral obligation to complete a deal is created and that, if it does use such fees, it not refund or credit them.

In addition, we believe that the BLM could benefit from further study of the best form of post-negotiation formal sale to use, the employee skills required for negotiating and the appropriate use of consultants to supplement them, the relative advantages of exchanges and cooperative leasing, the use of round-robin negotiations including the preferable form, the minimum number of tracts needed, and the percentage of coal in such negotiations the BLM should attempt to lease. The BLM should also study the use of final-offer arbitration, the trade-off between the percentage of lease negotiations that fail and the percentage of economic rent the BLM will receive, where along this trade-off the BLM should attempt to fall, the precise criteria for the selection of different lease sale mechanisms, and the advantages and disadvantages of BLM revealing its value estimates under various circumstances.

## PLANNED ACTIVITIES FOR FY 1987

This research has been concluded and no further activities are planned.

## SUGGESTED READING


1. Rothkopf, M. and McGuire, C.B. (1986), *Assessment of Negotiation Options for Coal-Lease Sales*, LBL-22501.
2. Chelius, J.R. and Dworkin, J.B. (1980), "An Economic Analysis of Final-Offer Arbitration," *Journal of Conflict Resolution, 24,* p. 293.
3. Cox, J.C., Smith, V.L., and Walker, J.M. (1983), "A Test that Discriminates Between Two Models of the Dutch/First Auction Non-isomorphism," *Journal of Economic Behavior and Organization, 4.*
4. Linowes, D.F., Chairman (1984), *Report of the Commission: Fair Market Value Policy for Federal Coal Leasing.*
5. Raiffa, H. (1982), *The Art and Science of Negotiation,* Harvard University Press.
6. Vickrey, W. (1961), "Counterspeculation, Auctions, and Competitive Sealed Tenders," *Journal of Finance, 16,* p. 8.

*LAWRENCE BERKELEY LABORATORY*
*TECHNICAL INFORMATION DEPARTMENT*
*UNIVERSITY OF CALIFORNIA*
*BERKELEY, CALIFORNIA 94720*