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FY 1985 Annual Report
ENERGY ANALYSIS PROGRAM

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LBL-20205

APPLIED SCIENCE DIVISION ANNUAL REPORT

ENERGY ANALYSIS PROGRAM

FY 1985

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

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ENERGY ANALYSIS PROGRAM

INTRODUCTION

The Energy Analysis Program is engaged in interdisciplinary activities in which analysts from different fields work together on issues of national significance. The Program's emphases on economics, public policy, and behavioral science distinguish it from other LBL activities. At the same time, however, engineering and technical analyses underlie its economic and policy studies, a foundation that distinguishes its work from that of most other analysis groups working on public policy issues. Virtually all of the Program's research and analysis is quantitative, and much of the research staff is engaged in developing and applying mathematical models.

At present, the work of the Energy Analysis Program emphasizes the study of energy use in buildings. This subject has been stressed for a number of reasons; one of the most important is the strong research effort within the Applied Science Division on energy conservation in buildings (especially the Energy Efficient Buildings and Solar Energy programs). The Energy Analysis Program provides a rigorous and extensive analytical and economic capability that complements the more technical pursuits of other groups in the Division involved in building energy research. The Program will continue to emphasize analysis of energy use and efficiency in buildings, and it is also applying techniques to other important national and international energy and resource policy issues.

The work of the program during fiscal year 1985 can be divided into the following groups of projects:

(1) Engineering and technical residential energy studies, including simulation studies and analysis of results of program survey data.

(2) Economic modeling, including studies of regulatory policies to reduce energy use of appliances and of heating and cooling equipment; studies of market behavior; development of models to valuate hourly and peak effects of conservation programs for residences; residential energy demand forecasting; analysis of the effects of energy conservation programs on electric and gas utilities; and analysis of governmental policies on transferring natural resources to the private sector for development.

(3) International studies of the structure and determinants of energy demand in developed and less developed countries.

The projects described in the following pages provide a solid start to a systematic analysis of the issues studied. Most of them will continue to expand and evolve. They can be expected to deepen our understanding of energy use and energy conservation in buildings. In addition, the Program is striving to expand its work to encompass other key energy and resource policy issues. In particular, international energy issues, critical energy price and supply questions, key resource and environmental issues, conservation program evaluations, and electric utility analyses are likely to constitute some of the new initiatives of the Program over the next few years.

Simplified Calculations of Energy Use in Residences*

R. Ritschard, Y. Huang, and J. Bull

Over the past five years, the Energy Analysis Program has compiled a comprehensive residential database using the DOE-2.1 computer program for five single-family prototypes (one-story, two-story, split-level, and end-unit and mid-unit townhouses), and two multi-family building types (end-unit and mid-unit apartments) with three foundation conditions (slab-on-grade, unheated basement, and ventilated crawl space) in 45 U.S. climates.

For each prototype building, foundation type, and location, we did a parametric set of 18 to 20 simulations to evaluate the energy impacts of typical conservation measures, such as ceiling, wall and foundation insulation, different window glazings and areas, and varying infiltration rates. The complete database consists of both base case parametric simulations and an equal number of DOE-2 runs for sensitivity analyses of optional measures including added south windows, reflective and heat-absorbing glazings, thermal mass, night insulation, whole-house fans, attached sunspaces, and night temperature setbacks. We used the single-family portion of this database to develop the DOE-sponsored energy slide rules and PEAR, a microcomputer version of the database.[1,2]

This article, which summarizes a more detailed LBL report,[3] describes simplified methods for estimating energy use in typical houses. In particular, we explain the *delta (Δ) load* format developed for the residential slide rules, and a more refined *component load* approach that has been incorporated into the PEAR microcomputer program.

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

ACCOMPLISHMENTS DURING FY 1985

Determination of Δ Loads

The DOE-2 database provides annual heating and cooling loads for selected packages of conservation measures in a prototype house for any of the 45 climate locations. We define Δ loads as the change in loads due to the addition of conservation measures. We have calculated them by comparing simulations in the database differing by only a single measure. We derive cumulative Δ loads for each component, e.g., ceilings or walls, by summing individual Δ loads for the same component. These cumulative Δ loads are actually composite values that assume all building components are being tightened simultaneously. For example, the Δ load for R-0 to R-38 ceiling is the sum of the Δ load from R-0 to R-19 ceiling on an uninsulated house, plus the Δ load from R-19 to R-38 ceilings on a moderately insulated house. For typical conservation packages, this procedure produces the most accurate Δ loads and minimizes interactions between different building components.

The Δ load approach is a convenient and easy to understand format for presenting the data. For each prototype and location, we have transformed the database into a series of Δ loads spanning the conservation measure simulated. For the energy slide rules, we show the Δ loads as linear distances on a series of tabs (see Fig. 1). By aligning the tabs, the user can calculate the total building load for any combination of measures by subtracting in analog fashion the Δ loads from a worst case base house. The Δ loads format gives an accurate representation of the database, but lacks flexibility for extending that data to building geometries and component characteristics different from those assumed in generating the database. Therefore, we analyzed this data further using linear regression procedures to establish the relationship between key building characteristics and component loads.

Determination of Component Loads

The Δ loads and base loads described above are prototype specific. They ignore changing surface-to-

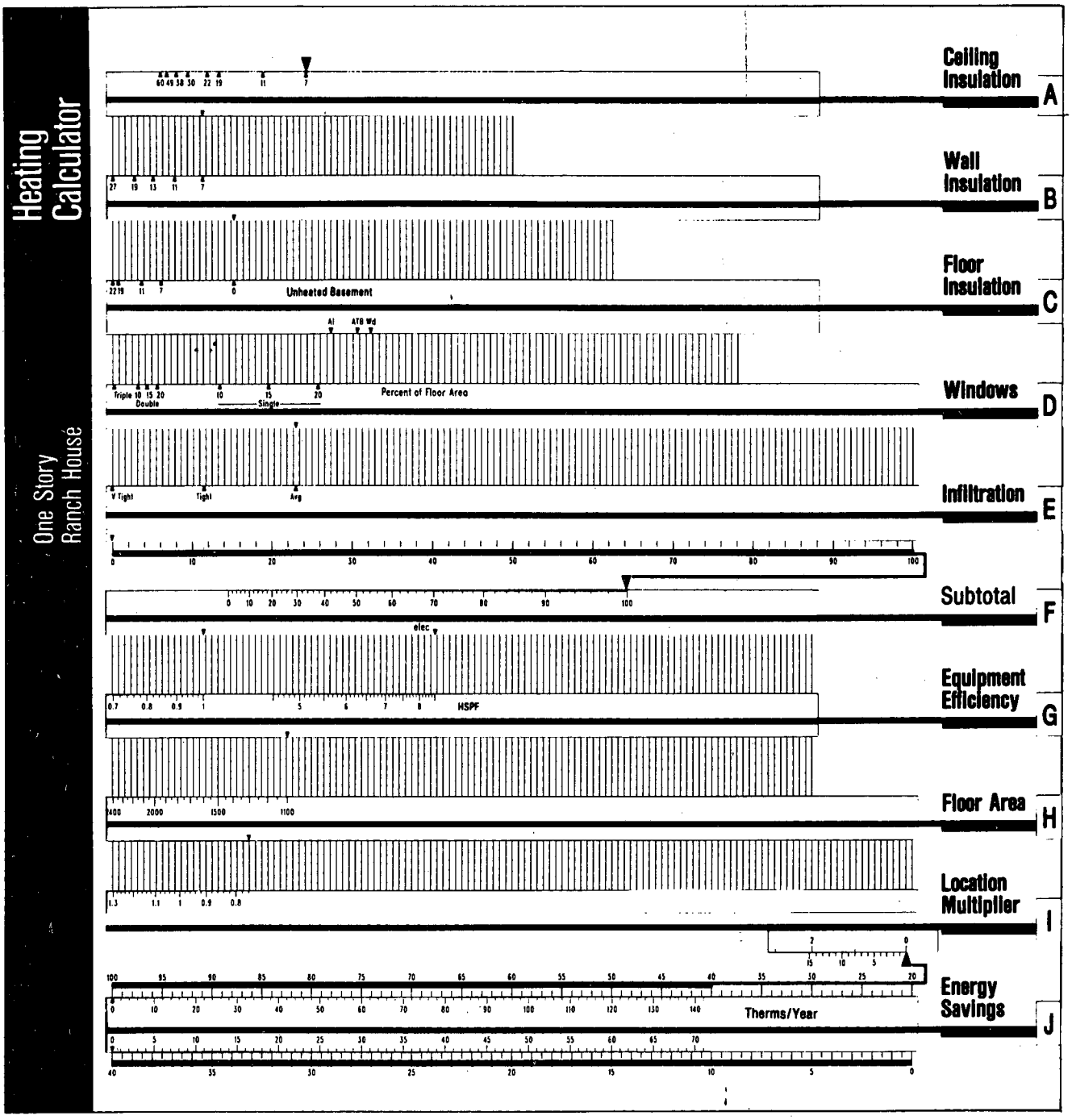

Figure 1. Heating calculator for one-story ranch house. (XBL 8312-2463)

volume ratios for varying sizes within one building prototype. This may, in turn, cause significant errors in estimating the Δ loads for houses where the ratios of wall-to-roof, window-to-wall, etc. differ significantly from those of the prototype house, leading to serious difficulties when the data are used for assessing tradeoffs between conservation options in homes differing substantially from the prototype.

To increase the flexibility of the database in handling different measures and prototypical designs, we developed the concept of component loads. We define *component loads* as the net annual contribution of each building component to the heating or cooling loads of the building. We have calculated them from regressions correlating the Δ loads to key physical parameters terms associated with the various building components. For insulation measures, we have regressed them against either ceiling or wall conductivity or total foundation conductance (as Btu/hr·ft^2·°F). For infiltration, we have regressed against air changes per hour; and for windows, against window area. As an example, Figures 2a and b show the relationship between heating or cooling Δ loads and ceiling conductance for a one-story ranch house in Washington, D.C.

Where the regression line meets the y-axis (y-intercept) the component loads can be assumed to be zero (i.e., zero conductance for the ceiling, etc.). We base the component loads for the simulated measures on the magnitude of difference (i.e., Δ loads) from the y-intercept (indicated on the right-hand scale of Figs. 2a and 2b). To facilitate scaling, we have normalized the component loads either per square foot (for ceiling, walls, and windows), per perimeter foot (for foundations), or per cubic foot (for infiltration). Since component loads correspond to the net loads for each component, they can be scaled by the actual amounts of ceiling, foundation, window, etc., thus making the database relatively prototype-free. The functional form of the regression equations also makes it easy to interpolate component loads for intermediate building design conditions using either adjacent component loads or general regression equations to describe the entire range.

There are two additional terms used in the component loads calculations, the *residual load* and the

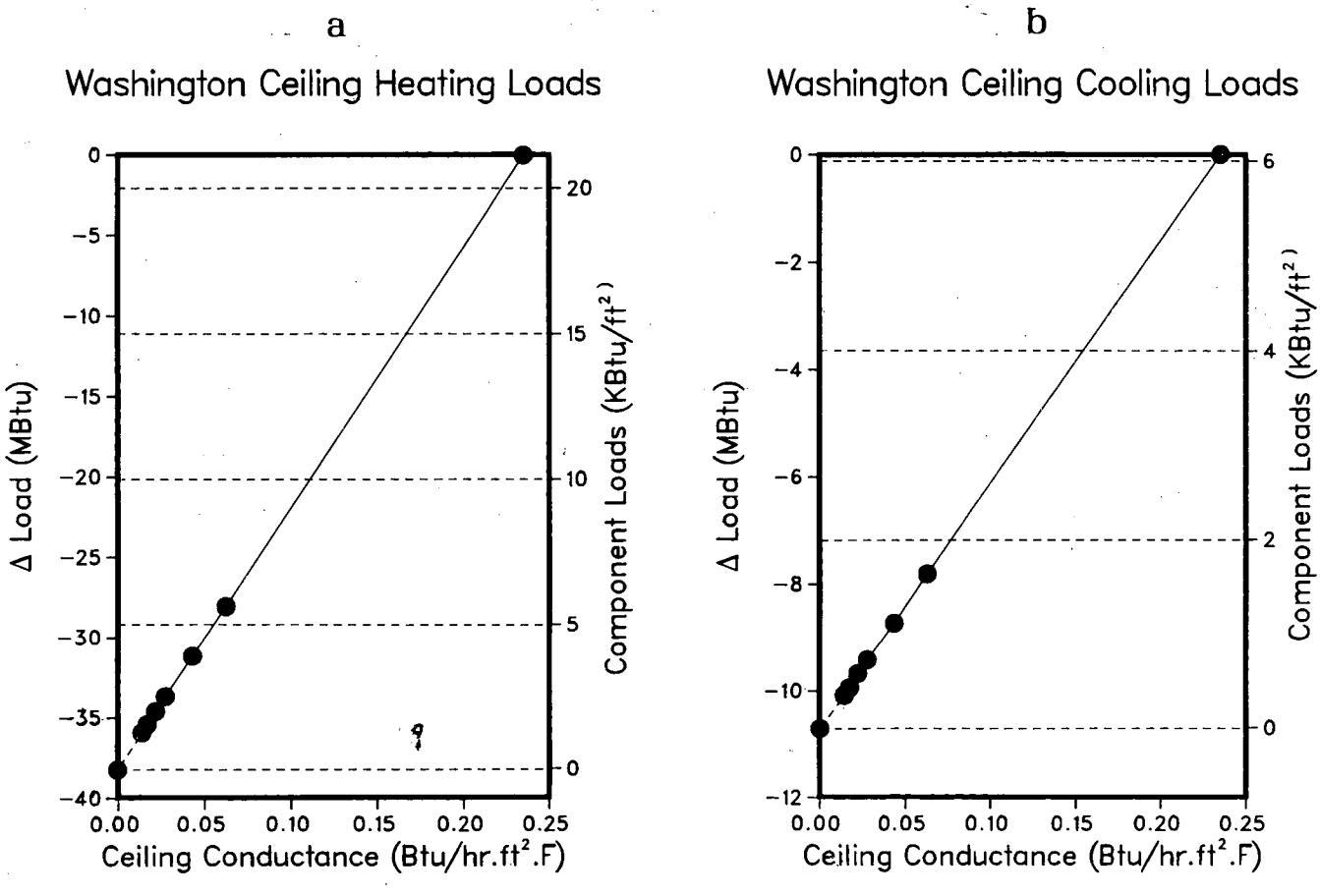

Figure 2. Ceiling heating (a) and cooling (b) loads in Washington, D.C. (XBL 8512-5192)

floor area adjustment. The residual load is the difference between the sum of the component loads and the total loads from the actual DOE-2 database. It represents the net effect of internal loads and interactions ignored in the component-by-component regression analysis. Since we held internal loads constant for each of the database simulations, we did not do component regressions for them. The predominant influence of internal loads on the residuals is evident in that they are always negative for heating and positive for cooling loads. The floor area adjustment is a secondary correction based on DOE-2 sensitivity analysis for each prototype with varying house sizes while keeping the aspect ratios and ceiling heights constant. Using the component loads approach, we develop a set of regression equations to calculate different floor areas (between 1000 ft^2 and 3000 ft^2) for the various building prototypes.

The component loads calculation requires a series of simple calculations that are too complex to incorporate into a mechanical slide rule, but are ideally suited for the microcomputer. We have incorporated this format into PEAR.[2] The component loads approach allows PEAR to adjust for different roof areas, wall areas and heights, perimeter lengths, and window areas to the point where the geometries of the original prototypes are of only incidental concern. At the same time, the regression equations allow PEAR to interpolate for intermediate component conditions.

Conclusions

The residential energy database developed in support of several DOE-sponsored programs provides benchmark numbers for determining the energy savings potential of typical conservation measures. Although databases are inherently less flexible than actual simulation programs, we describe a procedure to extend the database with good accuracy to the range of parametric options and designs found in typical houses. The procedure, which is based on the relationship between building component loads and key physical parameters, results in a set of regression equations that allow us to extend the simulation results to buildings with different geometries, conservation measures, and physical characteristics from those of the base case building prototype.

The results of our regression analysis also make it possible to compress the size of the data set, and to use it in novel ways. For example, if the relationship between the component loads and conductivities is known, it is easy to calculate the exact R-value necessary to achieve a certain reduction in load. We believe that the component loads approach, using simple linear regression equations, provides a accurate estimation of energy savings for typical residential conservation measures. The regression equations, which can be used in microcomputer programs like PEAR, extend the flexibility of the base case data. Results generated by such an approach lend themselves well to setting thermal performance levels for residential energy guidelines or building standards.

PLANNED ACTIVITIES DURING FY 1986

In FY 1986, we plan to extend the component loads approach in the following ways:

1. Investigate the relationships between total, component, and Δ loads for the 45 climate regions and building-related climate parameters, such as degree-days, latent enthalpy hours, heating and cooling insulation hours, etc. When we find reliable climate determinants, we can reduce the 45 geographical sets of data and develop extrapolation procedures to extend the data to other locations.
2. Identify the relationship between component loads for different prototype buildings, e.g., one-story versus two-story, detached versus attached, and single-family versus multi-family. Secondary terms may be added so that a single database can include all typical residential house types. This work includes additional analysis on the effects of internal loads, shading, and different surface-to-volume ratios on various component loads.
3. Expand and modify, if necessary, the simplified calculation procedure for heavy mass construction and for superinsulated houses.
4. Evaluate the relationship of window conductance, window sash, transmission, emissivity, and shading coefficients to window component loads. This analysis requires expanding the existing database to cover the parameters mentioned. The goal of this effort is a simplified calculation method that will allow users to choose any combination of window characteristics and shading assumptions.

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2. Ritschard, *et al.* (1985), *PEAR: A Microcomputer Program for Residential Energy Analysis,* LBL-20355.

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Survey of Low-Rise Multi-Family Building Practices*

P. Albrand, I. Turiel, R. Ritschard, and D. Wilson

The Building Energy Analysis Group at Lawrence Berkeley Laboratory (LBL) has been studying energy use in new low-rise multi-family buildings. The major objectives of this research are to: 1) gain a better understanding of the major determinants of energy use and power demand in multi-family residences, 2) evaluate the cost-effectiveness of conservation measures in various climates, and 3) transfer this information to builders of such housing and other interested parties. The research includes collection of data on energy use and building characteristics of new multi-family buildings, development of prototypical buildings, computer simulation, and energy and economic analysis.

Although multi-family dwellings accounted for about 38% (665,000 units)[1] of all new residential units built in 1984, there is surprisingly little published information on building characteristics available. Therefore, in order to satisfy a need for such data, we organized and convened a panel of builders of multi-family residences from across the country. With guidance provided by panel members, we produced a survey instrument especially designed to collect information on multi-family building characteristics.

Our preliminary findings covered a small number of multi-family buildings. Thus, the results were not generalized nor considered as statistically representative of new multi-family housing. However, we compare our survey results to previous studies, and to previous assumptions about multi-family prototypes, and identify several major research issues for the multi-family sector, such as developing new prototypical buildings and performing energy and economic analyses.

We first collected data on multi-family buildings from four major sources of information.[1-4] Multi-family housing includes all buildings with two or more living units. For the existing U.S. housing stock, multi-family buildings make up more than 26% of all residential units (see Table 1),[2] and about one third of all new residential units built each year are in multi-family buildings.[3] Most new multi-family units were built in the South and West. Three states (California, Florida and Texas) account for approximately 45% of all new units in buildings with five or more units, and seventy-five percent of all multi-family units built each year are in buildings with more than four units.[4] Although a major decrease in construction occurred in the residential

Table 1. Existing housing stock.[a]

	No. of units (millions)	% of total Units	Average heated floor space (ft^2)
Single family detached	53.8	64.2	1717
Single family attached	3.9	4.6	1535
2–4 units	10.1	12.1	1137
>4 units	12.2	14.6	795
Mobile homes	3.8	4.5	860
Total Residential	83.8	–	–

[a]1982 Residential Energy Consumption Survey: Housing Characteristics DOE/EIA-0314 (82), August 1984.

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

sector between 1979 and 1982, this did not affect the construction of multi-family units to the same extent as single-family units.

Multi-family housing consume more than 20% of the energy used by residential buildings, or more than 1.9 Quads out of a total of 9.5 Quads for all residential buildings.[2] Electricity is the dominant heating source for newly constructed multi-family housing units (see Fig. 1).[3] More than twice as many new units use electric heat as all the other fuels combined. During the last decade, the use of natural gas and oil for heating has decreased somewhat. In 1983, 89% of newly constructed multi-family units were air-conditioned.[3] In that same year, electric heat pumps were installed in 28% of new multi-family units.[3] Thirty-three of the 39 respondents in the NAHB survey[4] stated that individual heating ventilation and air conditioning systems (rather than central systems), would be chosen for new garden apartment projects over the next 3–5 years.

Low-rise buildings (1–3 stories) account for 86% of all new multi-family units[3] and thus represent most new multi-family housing. The average size of new multi-family units has varied between 900 and 1000 square feet over the last few years. Approximately two-thirds of these units are occupied by renters and the majority of those are individually metered.[3] Thus, there is little financial incentive for builders of such units to implement energy conservation measures.

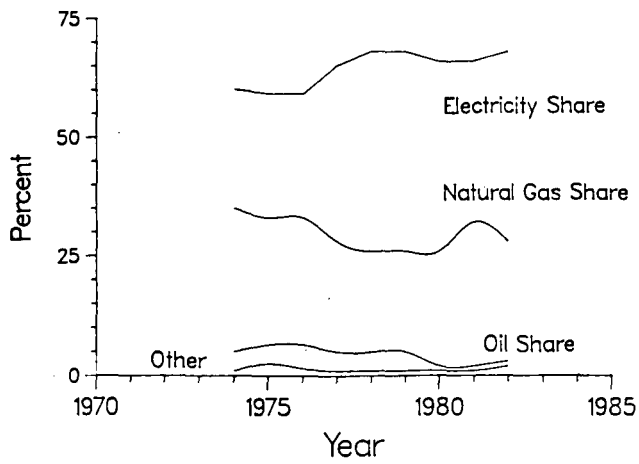

Figure 1. Heating fuel mix in multi-family units.

(XBL 862-447)

ACCOMPLISHMENTS DURING FY 1985

We developed a detailed 50-item survey instrument, recommended by the panel we organized, and sent it to 28 various builders across the U.S. The questions focused on building components, construction elements, typical architectural features, and space conditioning systems. There were two purposes in gathering these data: 1) to identify trends in multi-family construction characteristics and equipment use, and 2) to use these data to develop input to a building computer simulation program (DOE-2).

We achieved an overall 50% response rate, with 7 responses coming from the top 20 U.S. builders.* We attempted to contact builders in all typical U.S. climate regions, but concentrated our efforts in California, Texas and Florida. We decided not to weight our results (for percentage of builders and percentage of units), because of very consistent answers of the respondents. The survey respondents indicated that most of the buildings they constructed ranged from one story to four stories. Two- and three-story buildings represent almost 70% of the total, and over 80% are three stories and less.

Regarding the building envelope, our survey found that wall framing is generally 2×4 studs 16″ on center (O.C.), with plywood sheathing and interior drywall. The exterior wall is generally insulated (95%), with either fiberglass and a polyethylene vapor barrier, or rigid polyurethane insulation. Ten percent of the respondents report placing radiant barriers in the attic walls.

Ninety-five percent of the time, roofs are reported to be wood-frame, using wood rafters, with 1/2″ plywood sheathing covered by 1/8″ asphalt shingles or spanish tiles. Some of the builders use prefabricated roof structure, such as trusses and panels. Roofs are reported peaked 90% of the time, and of a medium-light color. All ceilings are reported insulated: either with fiberglass or rigid batts.

The most prevalent type of floor, reported in 45% of the survey responses, consists of 2×10 joists with slab-on-grade, basement and crawl space with a prevalence of slab foundations due to the extensive coverage of warm regions of the country (California,Texas and Florida).

*"Building Design & Construction," December, 1983.

The slabs, when they are insulated, have either insulation under the slab, or more commonly, perimeter insulation with an R-8 to R-10 value. The crawl spaces usually have insulation both under the floor and on the walls (R-19) and a polyethylene vapor barrier on the ground. Basement foundations appear generally to be used as garage space.

Eighty percent of the respondents reported they use regular window glass, with only 20% of them using tinted glass (typically in luxurious condominiums). The windows are generally equally distributed among the different orientations of the building, with an average window area of 10–12% of the floor area. No builders in the survey incorporated movable window insulation.

While passive solar strategies are not a prime consideration, 90% of the respondents in our survey are employing insulation and infiltration reduction (weatherstripping, caulking) and 20% are reported to use vapor barriers as a means to reduce energy consumption.

Our survey found that 95% of the apartments are reported to have individual heating and cooling systems. The type of installed equipment varies (see Table 2), but it should be noted that 57% are electrically heated. Natural ventilation (when the outdoor temperature allows it), and air conditioning remain the two major methods of cooling. The type of installed equipment varies, but it should be noted that 57% is electrically heated. The average seasonal energy efficiency ratio (SEER) of the air conditioners for the cooling systems is 8.25.

Typical appliances purchased and installed in the final installation of a typical multi-family building as reported in our survey are: ranges, electrical dishwashers, furnaces, water heaters, refrigerators, and garbage disposers.

The results of our multi-family survey, summarized in Table 3, are generally consistent with national data obtained from the Department of Housing and Urban Development. Locations with warm climates (California, Florida, Texas) are well represented by our respondents.

Table 2. Cooling equipment.

Type of equipment	Survey results (%)
Heat Pump	22.9
Air Conditioner	45.4
Other	31.6

Table 3. Summary of survey results.

GENERAL CHARACTERISTICS

Low-rise (1–3 stories) account for most new construction (75% are 2–3 stories).

Almost 90% of the buildings are rectangular in shape.

Average unit floor area equals 964 ft^2.

Typically, there are 12″ to 24″ overhangs on the eaves.

CONSTRUCTION CHARACTERISTICS

Walls

- 90% of the buildings have wood frame roof and wall construction.
- Wall insulation in 90% of the buildings varies from R-11 to R-19.
- Party wall insulation in 60% of the building varies from R-8 to R-13.

Floors/Ceilings

- Three types of floors are used: Slab-on-grade (70%) crawl-space (25%), basement (5%)
- Floor insulation in 42% of the buildings varies from R-8 to R-19.
- Ceiling insulation in the buildings varies from R-19 to R-33.

Windows

- Equal number of single and double glazing.
- Use of aluminum sash (53%) and wood sash 947%).
- Few special features: Reflective glazing, movable insulation, solar film.
- Window areas average 10 to 15% of the floor area of the building.

Infiltration

- Use of weatherstripping and caulk (90%).

Systems

- Individual heating and cooling systems (90–100%).
- Increasing use of heat pump (25.8%).
- Important use of air conditioner (46%).
- Use of temperature thermostat (20%).

PLANNED ACTIVITIES FOR FY 1986

The data obtained from both LBL and HUD surveys showed that the overwhelming majority of new units are in buildings with three or fewer stories. This supports our decision to study first low-rise multi-family buildings. Our initial assumptions used to model a two-story apartment building prototype[5]

appear to be valid. However, our survey results identified a need for a new 3-story prototype (26% of the respondents in our survey are building 3-story garden apartments). From the survey results, we also identified three major research topics that warrant further attention. They are internal loads patterns of multi-family buildings, building peak loads and space conditioning system type selection.

From our survey (and other studies), we found that most new low-rise multi-family construction is in hot locations and that almost all units in these areas use air conditioners for cooling. Therefore, it is important to study methods of reducing cooling energy use and peak demand in such buildings. The total building peak load in low-rise multi-family buildings could be lowered through improved design of a multi-zone building, by understanding the effect of orientation, by the use of thermal mass, by the optimum location of windows, and by the use of shading. Peak load reductions or shifts in loads to off-peak time, could lead to both consumer and utility company savings, if the utility company concerned uses off-peak rates. For example, San Diego Gas & Electric's costs for electricity drop from 11 cents/kWh during peak time to 7 cents/kWh during off-peak time. Utility company savings result from a lessened need to generate costly peak energy.

In order to study methods of reducing cooling energy use and peak power demand, we first need to improve our understanding of internal loads in multi-family buildings. The number of persons occupying a zone, the appliances used, and the lighting schedules determine the daily profile of internal loads within that zone. These load profiles for each zone are more difficult to determine in a multi-zone building such as a multi-family building, because the different zones are occupied independently of each other. In FY 86, we plan to gather measured data from existing building and test the sensitivity of different internal loads schedule in the simulation model.

Our survey results show that almost all space conditioning systems in new low-rise multi-family buildings are individual in nature. However, it may be more energy efficient to use central systems in some climates. The differences in heating and cooling loads for individual zones at any given moment of time can significantly affect the energy efficiency of a central HVAC system. We plan to study the use of individual space conditioning systems versus central or multi-zone systems, the use of new systems such as heat pumps, and the size and efficiency of the equipment versus the energy use.

Although our preliminary survey results are consistent with the earlier assumptions we made concerning low-rise multi-family construction characteristics, we need to determine whether these results hold for a larger database of new multi-family buildings and how construction characteristics vary with climate. Additionally, it is important to gather data on appliance saturations and use and occupancy patterns in order to determine better internal loads schedules. This will allow us to study more accurately strategies for reduction of cooling energy use and peak power demand in low-rise multi-family buildings.

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Energy and Economic Analysis of Conservation Measures for Low Rise Multi-Family Housing

I. Turiel, P. Albrand, and R. Ritschard

The Building Energy Analysis Group at Lawrence Berkeley Laboratory is studying energy use in new multi-family buildings. Multi-family units account for about 35% of all new residential units constructed each year. The principal objectives of this research are to gain a better understanding of the major determinants of energy use in multi-family residences and the cost-effectiveness of conservation measures in various climates and to transfer this information to builders of such housing. The research includes collection of data on energy use and building characteristics of multi-family buildings, development of prototypical buildings, and energy and economic analyses.

The present research project on multi-family housing focuses on new construction. Since low-rise buildings with more than four units account for most of the new construction and most of the energy use in the new multi-family housing sector, we analyzed this type of structure. Additionally, since much of the new construction is in the Sun Belt (i.e., South and West), we emphasized methods of reducing cooling energy use.

ACCOMPLISHMENTS DURING FY 1985

We began our research by collecting data on multi-family housing. We are interested in both energy use and construction characteristics data. Since the availability of such data is limited, we met with builders of multi-family residences and developed a questionnaire to gather additional information. We have analyzed the responses we have received to date (see preceding annual report article by Albrand, *et al.*). When this analysis is complete, we will develop new prototypical buildings. We developed the prototypical building used for the analyses described in this report with information obtained from discussions with builders and from data on new single-family housing construction. A preliminary analysis of early questionnaire returns indicates that our initial building characteristics assumptions are reasonable.

The parametric analyses described below were carried out with the computer program DOE-2.[1] We performed many simulations to determine the heating and cooling loads for each apartment within our prototypical building in different climates. We tabulated the reductions in space conditioning loads achieved by employing various conservation measures. We expressed the results for average end- and mid-units so that these average units could serve as building blocks for most other multi-family designs. That is, the heating and cooling load reductions we calculated for average end- and mid-units in the six-unit, two-story prototypical building can be used for similar units in other larger two-story buildings.

Our initial prototype is a two-story building consisting of six 1200 ft^2 apartment units. We also performed some simulations for floor space areas ranging from 900 to 2000 ft^2, allowing heating and cooling load reductions for a 1200 ft^2 apartment unit to be scaled upwards to a 2000 ft^2 unit or downwards to a 900 ft^2 unit. This prototype is representative of most two-story buildings with six or more units since the middle and end units in this six-plex will behave thermally like any similar units in a larger two-story building. We assumed a two foot fixed overhang on all four sides of the building. We performed simulations with window area for each unit equal to 10%, 15%, and 20% of the unit floor area. We modelled three types of foundations (ventilated crawl space, slab-on-grade, and unheated basement). Party walls between units are composed of four layers of gypsum board and R-11 insulation. We assumed the cooling setpoint to be 78°F and the heating setpoint to be 70°F with a nighttime setback to 60°F. Sensible internal loads are 53,100 Btu per day. We modelled infiltration to average 0.7 air changes per hour during the winter. A detailed description of the building construction characteristics and operating conditions can be found elsewhere.[2]

Using the prototype described above, we performed a number of sensitivity analyses with the DOE-2.1 computer program. These include studies of: ceiling insulation, wall insulation, foundation types with variable insulation, infiltration rate, window area, glazing type (number of glazings and reflective/absorptive glazing), floor area, roof solar absorptivity, movable nighttime insulation, thermostat setback, and building orientation. We simulated the building prototype with six separate zones, one for each apartment. Heating and cooling loads are obtained for each of the six zones. In order to reduce the quantity of data presented, we calculated the heating and cooling loads for average mid- and

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

end-apartment units. That is, the loads in the two mid-units and the four end-units are separately averaged and the results are presented separately for each. Therefore, these average results are applicable to two-story buildings only. Expressing the results as loads for average mid- and end-units, allows one to calculate the loads for other larger two-story buildings by using the results of this analysis for a six-unit building. The number of mid- and end-units are multiplied by the average mid and end loads, respectively and the two products are summed to give the total load for the larger building. We carried out many of the parametric studies for 45 climatically representative locations throughout the United States. In some cases, we performed simulations for 11 locations and developed regression equations to extrapolate the results to all 45 locations.

An example of the type of analysis we have carried out is the estimation of the effect of reflective glazing on cooling and heating energy use and on the cost of space conditioning. A detailed description of this analysis and also one of movable insulation can be found in another report.[3] We simulated the use of reflective glazing on all windows for the prototypical building described above in 11 locations. The reflectance for this glazing was 45% compared to the assumption of 6% for clear single-pane glass. We correlated changes in heating and cooling loads to average (of four cardinal directions) vertical insulation during the heating and cooling periods, respectively, obtaining the equations shown below.

Delta Heating Load (MBtu/ft^2) =

$$1.64 \times 10^{-3} + 2.0\times10^{-4} \cdot z \qquad (1)$$

Delta Cooling Load (MBtu/ft^2) =

$$2.71 \times 10^{-3} + 2.7\times10^{-4} \cdot y \qquad (2)$$

where

z = solar insulation (kBtu/ft^2) during the hours when there is a heating load,

y = solar insulation (kBtu/ft^2) during the hours when there is a cooling load.

Figure 1 illustrates the linear relationship between the delta cooling load and the average vertical insulation during the cooling period. We also performed similar analyses for double- and triple-pane windows and for delta heating loads. The correlation coefficients achieved with this regression analysis range from 0.95 to 0.99. We use the regression equations to predict heating and cooling load changes in other locations where the amount of vertical insulation is known but for which no computer simulations have been performed.

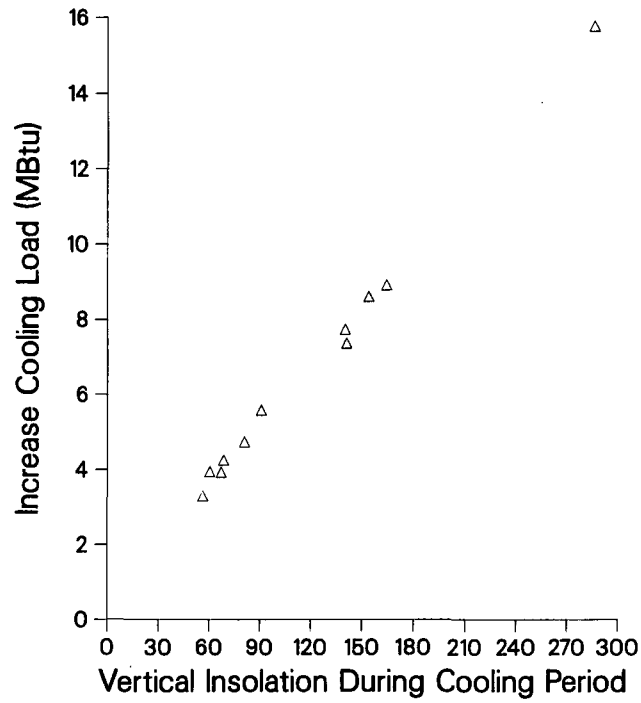
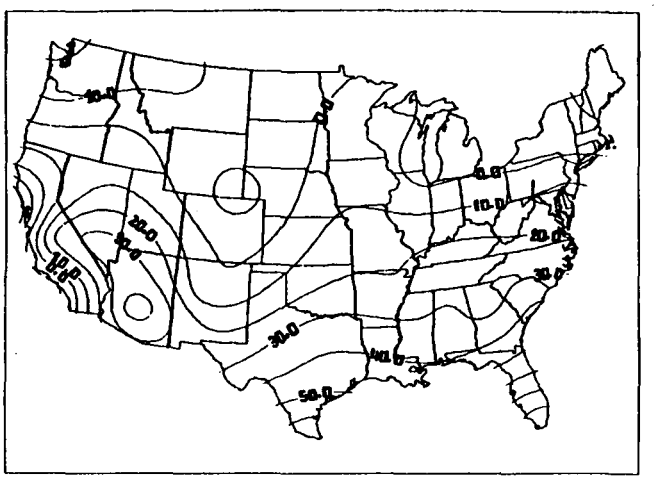


Figure 1. The effect of reflective glazing on cooling load plotted for eleven locations as a function of average vertical insolation (kBtu/ft^2) during the cooling period. (XBL 851-992)

We have also assessed the cost effectiveness of using reflective glazing. Figure 2 shows on a map of the United States the change in the annual cost of space conditioning (1985$/yr) for 100 ft^2 of reflective single-pane glass relative to the single-pane glass described for the base case end unit apartment. It is important to note that the values shown on the map are approximate for locations between the 45 cities for which we calculated space conditioning costs. We assumed a gas space heating system with a seasonal COP of 0.7 and an electrical cooling system with a seasonal COP of 2.4 (SEER = 8.2). We assumed the costs of electricity and natural gas were $0.08/kWh and $0.50/therm, respectively, for all locations.

The cost savings are substantial (30–80$/yr) in climates with warm summers and mild winters; e.g., in southwestern and southern parts of the U.S. these savings would be proportionally higher for apart-



GAS SPACE HEATING

Figure 2. The impact of reflective glazing on the annual cost ($985) of space conditioning a 1200 ft^2 end-unit apartment with 100 ft^2 of single-pane windows is shown on a map of the U.S. The cost changes are for an apartment heating with natural gas and cooled with an electric air conditioner. (XBL 8512-5070)

ments with more than 100 ft^2 of window area. The savings moderate as one moves north to cooler locations. In the Pacific Northwest and parts of California, Idaho, Montana and Nevada, space conditioning costs increase with the use of reflective glazing. The additional capital cost of reflective glazing is approximately $4.00 per square foot.[4] The map should be used to determine which regions of the U.S. are likely to have reasonably short (<10 yrs) simple payback periods for the use of reflective glazing. The simple payback period is obtained by dividing the additional capital cost of reflective glazing by the annual dollar savings shown on the map. Therefore, the simple payback period is 5–13 years for an end-unit apartment with gas space heating in the southwestern or southern parts of the U.S. Electrically heated residences will have longer payback periods.

PLANNED ACTIVITIES FOR FY 1986

Using computer simulations, we have quantified reduced space conditioning loads that result from added thermal insulation, nighttime thermostat setback, decreased infiltration, and proper choice of orientation and glazing. We plan to perform additional cost-benefit analyses to determine the cost-effectiveness of specific measures in various locations. Local fuel prices and other heating and cooling equipment types will be incorporated into the economic analyses. We are developing a microcomputer program that will allow such calculations to be made in an easy to use and inexpensive manner. In the next phase of our work, we will analyze additions. Local fuel prices and other heating and cooling equipment types will be incorporated into the economic analyses. We are developing a microcomputer program that will allow such calculations to be made in an easy to use and inexpensive manner. In the next phase of our work, we will analyze additional conservation measures (e.g., external shading) and additional prototypical low-rise apartments. We also plan to develop a three-story prototype in order to broaden our coverage of low-rise multifamily housing. With the addition of this prototype, we will be able to apply the building block approach to almost any low-rise multi-family building.

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Potential for Wind Induced Ventilation in Residences*

S.J. Byrne, R.L. Ritschard, and D.M. Foley

Wind induced ventilation of buildings can be a significant means of increasing occupant comfort and reducing cooling energy consumption in hot climates. In FY 85, the Building Energy Analysis Group began investigating the magnitude of this savings and how buildings might be better designed to enhance it. This paper describes the first phase of that work—the development of a simple graphic tool that enables a building designer to evaluate the potential for wind induced ventilation cooling in several climate zones. The graphic format is similar to conventional "wind roses" that are currently used by designers, but with the additional effects of human comfort and building cooling load taken into account.

This design tool allows the user to determine: (1) the human comfort level when the interior wind speed is at various fractions of the available exterior wind speed, (2) the building cooling load for those ambient conditions that are uncomfortable, and (3) the direction the wind is blowing from when mechanical cooling is required to maintain comfort.

Thus, the results indicate the potential savings from inducing various ventilation air flow rates as well as the orientation of building openings that will minimize the annual cooling load. Local weather patterns, such as strong northerly winds, combined with lower air temperature during brief storms (in which case mechanical cooling could be unnecessary) are automatically accounted for and are weighted by the frequency of occurrence.

ACCOMPLISHMENTS DURING FY 1985

In order to properly size and orient building openings to take advantage of ventilation cooling, a designer must be aware of local wind speed and direction as well as coincident ambient dry bulb and relative humidity. The designer must then determine the impact of the combination of wind speed, temperature and humidity on human comfort and the resulting effect on the building cooling load.

The research on this project was organized to solve these problems and was composed of three parts: (1) analysis of long term weather data, especially coincident wind speed and direction, dry bulb temperature and relative humidity, (2) mathematical modeling of the effects of wind speed on human comfort under conditions of high temperature and humidity, and (3) development of a simplified model of residential building cooling load that correlates with data from DOE-2 simulations.

Analysis of Weather Data

Summary information on wind direction, frequency, and prevailing wind speed is available as "wind rose" plots[1] of conditions at local weather stations. Although this information has traditionally been used as an indication of average local wind conditions, its usefulness in building design is very limited. Wind rose plots (see example in Fig. 1) indicate frequency of wind blowing in each of 16 directions and wind speed is given for the prevailing wind direction. This provides a designer with no information on coincident temperature and humidity, which must be used to determine whether ventilation is beneficial. Although it is possible to use monthly wind roses together with monthly average weather data,[2] the designer is at best, left with a rough estimate that indicates little about the effect on human comfort and building cooling loads.

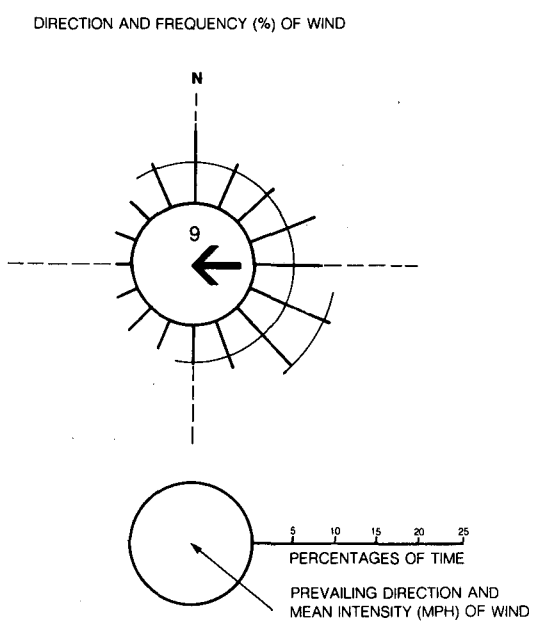

Figure 1. Annual wind roses for Miami. (XBL 859-3897)

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

Hourly weather data are available in a variety of formats and can be obtained for multiple, contiguous years[3] or for a single, average year.[4–6] For this analysis, we chose to analyze long term (approximately 12 contiguous years) data for each location, because the methods for determining "average" years emphasize average temperature and solar radiation but not wind speed or direction. We used data from years prior to 1965, when reporting frequency was changed from hourly to once every three hours at most locations. Available weather tapes begin during mid 1952 through early 1953, thus yielding approximately 12 years of hourly data for each location. Our summarized results, therefore, represent average potential for wind induced ventilation cooling and may not be exactly the same for any specific year.

Because this analysis is intended to show the benefit of ventilation cooling in buildings, the wind speed measured at the local weather station (usually a nearby airport) was translated to what could be expected at the building site, accounting for: (1) the difference in height between the wind tower at the weather station and a typical building height, and (2) the difference in terrain between a typical weather station and a typical residential building site.[7]

In this work, we converted the weather station wind speed to a height of 3 meters in a suburban area. The wind direction was unchanged from the measured value. This represents the available wind speed and direction for ventilation cooling of most single family houses. Local obstructions (e.g., large, nearby buildings, trees or hills) might reduce the wind speed or alter the direction and should be accounted for in the actual building design.

Mathematical Modeling of Human Comfort

To be acceptable to its occupants, a built environment must provide thermal comfort. Achieving thermal comfort depends on both environmental and personal factors, some subject to the occupants' control, and others not. The important environmental determinants of thermal comfort are temperature, humidity, radiation and air movement, while important personal factors are clothing and activity level.

Because thermal comfort and discomfort are subjective sensations, it is difficult to predict the effects of any combination of environmental and personal factors. However, sensations of comfort or discomfort correlate with physiological quantities which can be measured or calculated (e.g., skin temperature, body core temperature, rates of sweating and breathing, etc.). Reported thermal sensations from human test subjects have been compared with physiological measurements, and from these data, researchers have been able to develop mathematical models and computer algorithms to predict the response of a person to a given thermal environment, taking into account that person's clothing and activity level.

Three of the most widely used comfort algorithms are the Fanger Comfort Model, developed by P.O. Fanger of the Technical University of Denmark,[8] the Pierce Two Node Model, developed by A.P. Gagge and colleagues at the J.B. Pierce Foundation,[9] and the KSU Two Node Model, developed by N.Z. Azer and colleagues at Kansas State University.[10] A comparison of the three algorithms is given by Berglund.[11] For the work which led to this paper, we used a modified version of the Pierce Two Node Model.

Humans regulate their heat exchange with the environment in order to maintain, within a very close tolerance, the temperature of their body core. The Pierce model describes this heat exchange process by modeling the human body as two discrete compartments: an inner core and an outer skin. The core, which is assumed to be of uniform temperature, is modeled as the source of all metabolic heat production. To maintain a constant core temperature, all of the metabolic heat and work must be transferred to the surroundings. In the model, the core transfers energy directly to the environment through respiration and work. The remaining metabolic heat is transferred to the skin compartment, both passively by conduction and actively by the controlled flow of blood from the core to the skin. The skin gives off heat to the environment through convection, radiation, evaporation of sweat and diffusion of water vapor through the skin.

From the values of physiological variables calculated in the model, the discomfort index can be determined. In the version of the Pierce model that we used, the discomfort index, DISC, is calculated by:

$$\mathrm{DISC} = 5.0 \cdot \frac{\dfrac{(0.68 \cdot E_{rsw}) + E_{dif}}{E_{max}} - P_{wet}}{1.0 - P_{wet}} \qquad (4)$$

where:

E_{max} = maximum rate of evaporation of sweat (W/m^2),
= $(P_{sk} - P_a)/[1/h_{cl} + 1/(16.5h_c)]$;
P_{sk} = saturation vapor pressure at skin temperature (kPa);
P_a = partial vapor pressure at air temperature (kPa);

h_{cl} = moisture conductance of clothing (W/m^2kPa),
= $115 / I_{clo}$;
I_{clo} = thermal resistance of clothing (clo);
h_c = convective heat transfer coefficient (W/m^2K),
= $8.6 \cdot V^{0.56}$;
V = air velocity (m/s);
P_{wet} = fraction of skin wettedness (dimensionless),
= $0.08 \cdot ACT / 58.2 - 0.02$;
ACT = metabolic heat from activity (W/m^2).

Each of the environmental determinants of thermal comfort has some influence on the discomfort index. In our work, we assumed that the mean radiant temperature of the building is equal to the dry bulb temperature, which is often the case for light weight residential construction. We also assumed the occupants are not directly exposed to solar radiation. Therefore, the influence of radiation in the model was negligible.

We tested the sensitivity of the model to temperature, humidity, air movement, activity level and clothing. Figure 2 shows the discomfort index (DISC) as a function of dry bulb temperature, relative humidity and wind speed. The rate of increase in DISC with temperature is significantly higher at 80% RH than at 20% RH. Likewise, the impact of wind speed on comfort is greater at higher humidity and temperature levels. Thus, a combination of increasing temperature and humidity affects comfort more than either parameter alone and the use of wind to provide occupant comfort is more significant in hot-humid climates than in hot-arid climates. A similar parametric analysis was made to determine the sensitivity of the model to activity level and clothing. Increasing the activity level increases metabolic heat production (met), and thus, at high ambient temperatures, increases thermal discomfort. The rate of increase of discomfort with activity level is greater when the amount of clothing (clo) value is greater, because clothing acts as an impedance to heat dissipation.

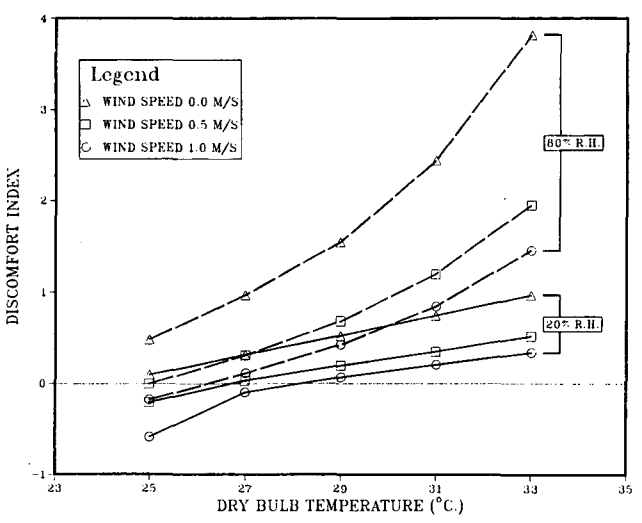

Figure 2. Discomfort index (DISC) as a function of dry bulb temperature, relative humidity and wind speed. (XBL 859-3884)

In our work, we assumed a clo value of 0.5, corresponding to light clothing suitable for office or home in a warm climate. We set the activity level at 1.1 met, representing a person working at a desk, reading or watching television.[12] Further, we set the maximum acceptable interior wind speed to 1.0 m/s, since any wind above that speed is likely to cause papers to rustle and may be irritating to occupants. We set the discomfort index at which a person is likely to turn on an air conditioner to 0.5.

Estimating Building Cooling Load

A reliable indicator for building cooling loads should recognize latent as well as sensible cooling loads. Data from a LBL data base of DOE-2.1A loads for a typical 1-story residential prototype in 45 U.S. locations showed latent percentages varying from 5% for an uninsulated house in arid Phoenix to 35% for a moderately well-insulated house in Miami. Therefore, climate parameters based only on temperature differences, such as cooling degree days or degree hours, can be substantially in error for estimating cooling loads. This was confirmed in comparisons made between the cooling loads and degree hour data for the same locations.

To incorporate the effects of latent cooling, we used the concept of cooling enthalpy hours. Enthalpy hours define the amount of energy that must be removed from the air each hour to lower ambient air conditions to a reference condition defined by dry bulb temperature *as well as* humidity ratio. Cooling enthalpy hours can be further divided into sensible and latent components. The sensible component is proportional to cooling degree days and is useful for estimating sensible loads using standard $UA\Delta T$ calculations. The latent component can be related to latent cooling loads for a given infiltration rate.

On a psychometric chart, cooling enthalpy appears as the difference in enthalpy between the ambient air condition and the reference point. Latent enthalpy is the enthalpy reduction necessary

to lower humidity ratios to the reference level, keeping the dry bulb temperature fixed. Sensible enthalpy is the additional enthalpy reduction necessary to lower the dry bulb temperature to the base temperature, keeping the humidity ratio constant. Therefore, latent enthalpy corresponds to a vertical movement, and sensible enthalpy to a horizontal movement on the psychometric chart. The total change in enthalpy times the number of hours that condition exists equals the number of enthalpy hours.

The reference dry bulb temperature for calculating enthalpy hours is interpreted, similar to cooling degree days, as the balance point or threshold ambient temperature above which mechanical cooling will be required to maintain the indoor temperature specified by the thermostat set point. Because of solar gain, we used reference temperatures of 18°C for the daytime, and 24°C for the nighttime hours. We calculated the balance point temperatures assuming a typical 143 m^2 prototype house with 0.30 $W/m^2{}^\circ C$ ceilings, 0.52 $W/m^2{}^\circ C$ walls, and 0.5 ach infiltration. More details on the prototype house and operating conditions as well as the LBL data base are given by Huang.[13]

The reference humidity ratio is more difficult to define, since cooling controls in residential systems generally respond only to indoor temperature and not to humidity. For this study, we chose a humidity ratio of 0.0116 (kg of moisture/kg of dry air), corresponding to the upper limit of the human comfort zone.[12] This humidity ratio is chosen on the assumption that a properly sized air conditioner will maintain indoor comfort by keeping the humidity ratio below this level. Latent loads from the LBL residential data base correlate well with latent enthalpy hours at 0.0116 base humidity ratio.

We imposed two conditions on the calculations: (1) latent enthalpy hours are not counted when sensible enthalpy hours are nonpositive; and (2) negative latent enthalpy hours are set to zero. The first condition assumes that the air conditioner will be off because the ambient air is cool, even though it has more enthalphy content than the reference point. The second condition assumes that typical residential cooling systems do not humidify even though ambient air conditions may be hot and dry.

The relationship of sensible and latent enthalpy hours to cooling loads for a particular house depends on its total conductance and infiltration rate. For this study, we assume an average summer infiltration rate of 0.5 ach (air changes/hour) for a prototype 1-story house with a volume of 348.9 m^3. The latent load (kJ) is estimated from latent enthalpy hours by:

$$Q_{lat} = HH_{lat} \cdot V \cdot \rho \qquad (6)$$

where:

HH_{lat} = latent enthalpy hours (kJ-h/kg dry air);
V = volumetric air change rate (348.9 $m^3/h \cdot 0.5$);
ρ = density of air (1.2 kg/m^3);
or:
$Q_{lat} = HH_{lat} \cdot 209$ kg/h.

The sensible load (kJ) is estimated from sensible enthalpy hours by:

$$Q_{sen} = (HH_{sen} \cdot V \cdot \rho) + (HH_{sen} \cdot UA) \qquad (7)$$

where:

HH_{sen} = sensible enthalpy hours (kJ-h/kg dry air);
V, ρ = same as for Q_{lat} above;
UA = building conductance,
= 1055 kJ/h-°C;
or:
$Q_{sen} = (HH_{sen} \cdot 209) + (HH_{sen} \cdot 1055)$
$= HH_{sen} \cdot 1264$ kg/h.

The estimated total cooling load (kJ) is then:

$$Q_{total} = (HH_{lat} \cdot 209) + (HH_{sen} \cdot 1264) \qquad (8)$$

The predicted cooling load using this model was compared to a large data base of DOE-2.1A simulations in 45 cities. The resulting high correlation coefficient indicates an accurate estimation of both the latent and the sensible fractions of the total annual cooling load.

Applications

An example of the resulting plot of building cooling load versus wind speed and direction is shown in Fig. 3. The center of each plot represents zero cooling load and the outerost circle is the maximum cooling load (shown as Q_{max}) while the wind is blowing in any single direction. Thus, the scale on each plot varies so that the resolution can be kept as large as possible. The contour lines represent the building cooling load at various percentages of the outside wind speed. The outermost (solid) contour line is for the case of no ventilation; the next (dashed) contour line inward is the cooling load with 20% of the outside wind speed available for ventila-

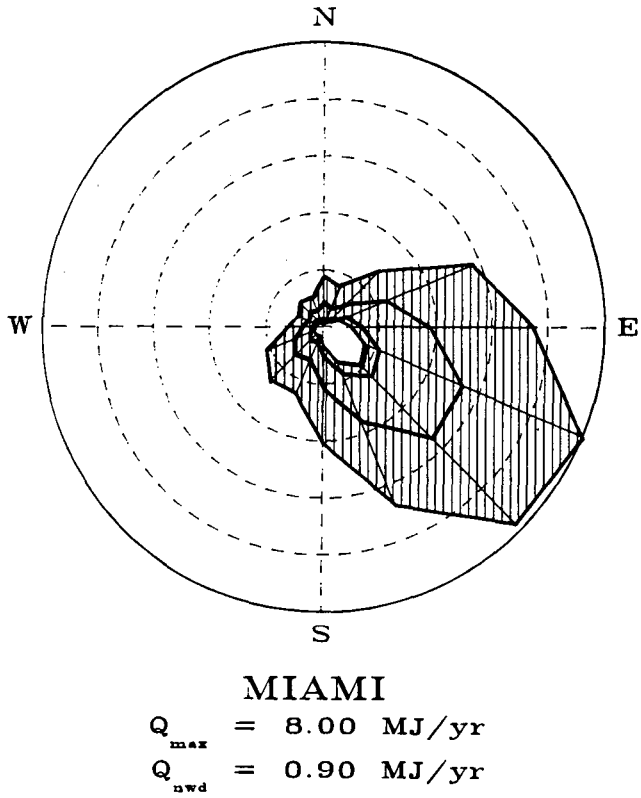

Figure 3. Plot of building cooling load versus wind speed and direction. (XBL 859-3889)

tion. Contour lines alternate between solid and dashed lines and are plotted for 0%, 20%, 40%, 60%, and 100% of the outside wind speed. In addition to the cooling load while the wind is blowing, there is a load during periods of no wind (shown as Q_{nwd}) that should be accounted for in any annual energy calculations.

The primary usefulness of these plots is in the ability of a designer to assess quickly the potential benefit of ventilation cooling and the impact that it will have on orientation of a single building or an entire subdivision. This can be accomplished early in the design process to ensure that subsequent design decisions do not conflict with the ventilation scheme.

Figure 4 shows total cooling load, as a function of interior wind speed, for several cities. The hot-humid climates show a significant reduction in annual cooling load up to high fractions of the outside wind speed, while most of the potential savings in hot-arid climates is realized at lower wind speed fractions. This indicates the importance of properly designing buildings in hot-humid climates to induce natural ventilation.

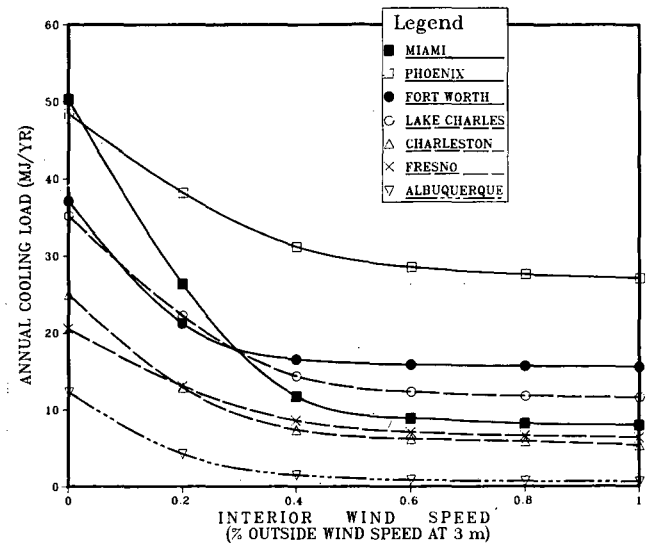

Figure 4. Total cooling load as a function of interior wind speed. (XBL 859-3883)

It is important to note that these plots account only for the impact of ventilation on cooling load and a building designed for minimal energy consumption should also account for the effects of solar gain. It may be necessary to design ventilation openings that are well shaded from direct solar radiation in order to prevent the additional solar gain from offsetting the benefits of ventilation.

PLANNED ACTIVITIES FOR FY 1986

In this paper, we do not propose the means by which any particular ventilation rate can be induced in a building. Continuing research in this area will utilize air flow simulation models and a wind tunnel to explore design alternatives that enhance the natural ventilation of buildings. This work will be started in FY 86 with wind tunnel studies of ventilation design strategies. Long term results of this project will be simplified design guidelines and mathematical models to predict air flow rates in arbitrary building shapes.

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Residential Prototype Loads Comparisons*

R. Sullivan, Y.J. Huang, R. Ritschard, I. Turiel, and J. Bull

ACCOMPLISHMENTS DURING FY 1985

The Building Energy Analysis Group at Lawrence Berkeley Laboratory has been extensively involved in investigating residential energy use in prototypical houses in the United States. This research has centered on evaluating the influence of various energy conservation measures such as exterior surface insulation, glazing type and conductance, infiltration levels, use of night setback, etc. One of the more recent projects has been the definition and development of a very large data base constructed from numerous DOE-2 building energy simulations of five residential prototypes.

*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.

The original purpose for the data base was the development of simplified energy analysis tools capable of accurately estimating the energy savings associated with particular conservation measures.[1-3] These tools were designed for use by non-technical groups such as home builders, home buyers, and others in the building industry. The availability of such a large number of building energy simulations permits a more detailed analysis of a broad spectrum of residential building design issues. The work reported here is related to such an analysis with emphasis on the relationship among building prototypes and configurations and their variation with geographic location.

A thermal load comparison of five residential prototypes was accomplished along with a discussion of the implications associated with varying configuration parameters and geographic locations. A data base constructed from DOE-2.1A computer simulations for five building models (one-story ranch, two-story, split-level, middle-unit townhouse, and end-unit townhouse) with a climate base of 17 locations was used for the analysis. Also investigated were the differences associated with three floor types: slab-on-grade, basement, and ventilated crawl space. Results indicate that the thermal loads of various prototypes are proportional to each other in a manner that is independent of geographic location.

In addition, percent heating and cooling load changes for a particular prototype resulting from implementation of a conservation measure are also approximately constant with location. An analysis of multiple-regression-derived algebraic formulas established conditions for exact or approximate linear independence of a building's heat gain or loss components. Procedures were also defined for the simplification of future parametric studies of the thermal analysis of buildings using a methodology that incorporated the observations reported.

Intra- and Inter-Prototype Thermal Load Relationships

Reference 4 described the development of a proportional relationship between residential building thermal loads for varying configuration parameters. Through the use of numerous building energy simulations using both the DOE-2.1 and BLAST energy analysis computer programs, it was shown that the form of the relationship was independent of climatic location and covered a broad spectrum of those variables. The study concentrated on the relationship prevalent among varying configurations of the same basic prototype residence. A second study,[5] concentrated on the relationship that exists across prototypes, which of course leads to much more general conclusions regarding the significance of the results.

Figures 1 and 2 represent the basis for investigation of the proportionality expressed by the figures, i.e., the linear relationship associated with configuration changes as a function of geographic location. Thermal load values due to implementation of specific conservation measures are shown for the

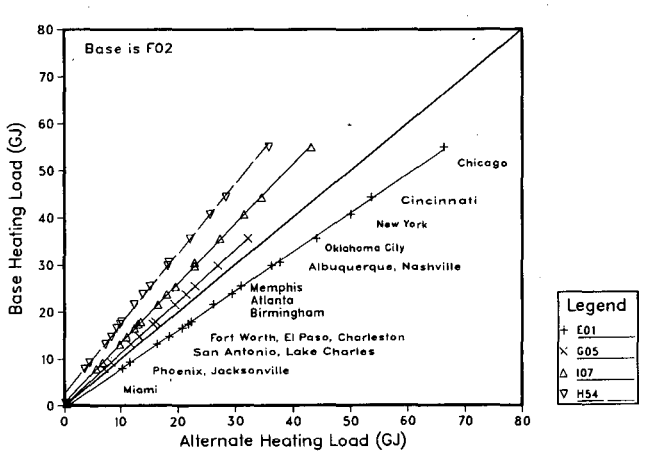

Figure 1. Residential heating load comparison for various configurations and geographic locations (TRY) using DOE-2.1A for a one-zone (143 m^2), ranch style, slab-on-grade house showing the effects of envelope conductance and infiltration. (XBL 8512-4977)

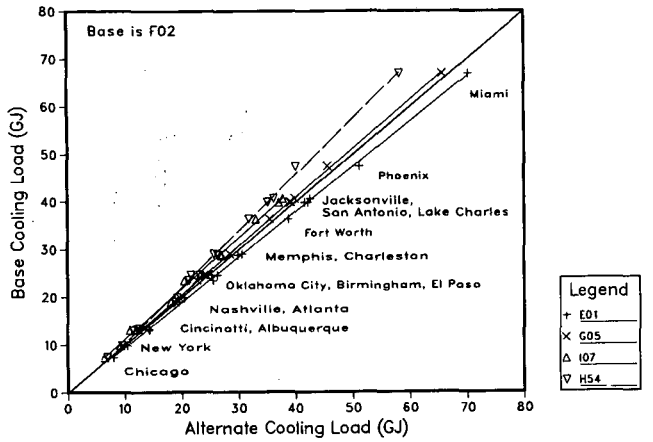

Figure 2. Residential cooling load comparison for various configurations and geographic locations (TRY) using DOE-2.1A for a one-zone (143 m^2), ranch style, slab-on-grade house showing the effects of envelope conductance and infiltration. (XBL 8512-4975)

slab-on-grade, ranch prototype using configuration F02 as a base. The slopes of the curves on these figures are presented on Table 1. They correspond to

Table 1. Heating and Cooling Load Ratios for Five Residential Prototypes and Four Configurations (Slab-On-Grade Floor) Using F02 as a Base Load (Alternate Configuration)/Load (Base Configuration F02)

Prototype	Configuration	Heating	Cooling
Ranch	E01	1.22	1.06
	G05	.91	.98
	I07	.77	.92
	H54	.61	.88
Two-story	E01	1.25	1.06
	G05	.88	.97
	I07	.76	.92
	H54	.59	.87
Split-level	E01	1.27	1.06
	G05	.89	.97
	I07	.75	.91
	H54	.59	.88
End-townhouse	E01	1.33	1.06
	G05	.88	.97
	I07	.74	.93
	H54	.57	.90
Mid-townhouse	E01	1.39	1.06
	G05	.93	.99
	I07	.76	.94
	H54	.56	.91

the ratios of the alternate loads to the base loads. Data for the complete set of five prototypes using the slab-on-grade floor are shown in the table. Although the intercepts on the figures do not go exactly through the origin, the approximate relationship between configurations can be ascertained using only the slopes.

The base configuration, F02, corresponds to R=19 (3.34) roof insulation, R=11 (1.94) wall insulation, an equivalent floor U-value of 0.4 (0.69), double-pane glass, and 0.7 air-changes per hour of infiltration. Configuration E01 shows the change in load when using single-pane glass. Heating load increases from a low of about 22% of the base level for the ranch style house to a high of 39% for the mid-townhouse. The cooling load increases by 6% for all prototypes. G05 indicates the effect of increased wall insulation, R=19 (3.34). Almost no change in cooling is apparent; however, there is a 12% reduction in heating for those prototypes with a large percentage of wall surface area. Configuration I07 has increased roof, wall, and glass resistance values, and therefore a significant reduction in load is apparent for all prototypes, particularly heating. The percent change in heating is about equivalent to that resulting from a switch from single pane to double pane glass. H54 shows the largest reduction in thermal load with the decreases varying from 39% to 44% for heating and 9% to 13% for cooling. The H54 values are a result of both increased roof and wall insulation (R=30 and R=19), and a decrease in the average infiltration rate to 0.4 air-changes per hour.

The significance of Figures 1 and 2 is that the slopes or percent increase or decrease in load are approximately the same regardless of geographic location. Surprisingly, the same type of proportionality results when comparing the various prototypes. For example, Figures 3 and 4 present results for configuration F02 for all five prototypes for the slab-on-grade floor for seventeen climate locations. The base prototype values, which are presented along the vertical axis, represent the one-story ranch. Load values for the other four prototypes are along the horizontal axis. Heating and cooling correlate with house size; i.e., the largest load is associated with the largest surface area and/or largest floor area. Heating, in particular, is well behaved because of the strong influence of house conductivity. The two-story has the largest loads followed by the split-level, ranch, and end- and mid-townhouses. Using the slopes of Figures 3 and 4, one can quickly obtain an estimate of inter-prototype relationships similar to the data contained in Table 1.

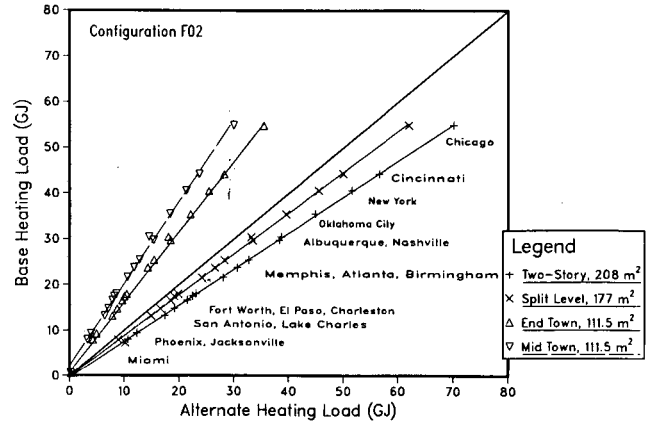

Figure 3. Residential heating load comparison for various prototypes and geographic locations (TRY) using DOE-2.1A. The base prototype is a one-zone (143 m^2), ranch style, slab-on-grade house. (XBL 8512-4974)

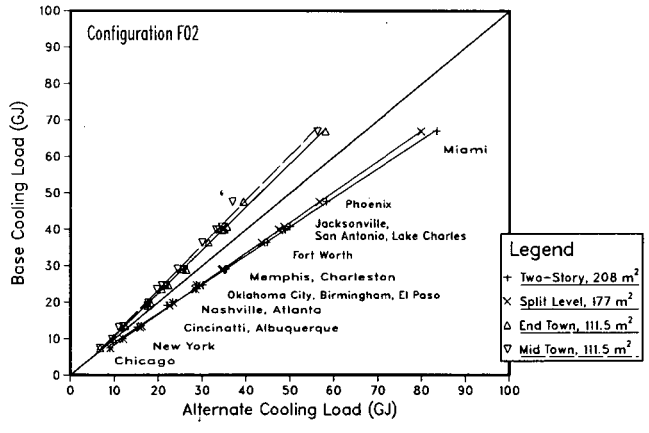

Figure 4. Residential cooling load comparison for various prototypes and geographic locations (TRY) using DOE-2.1A. The base prototype is a one-zone (143 m^2), ranch style, slab-on-grade house. (XBL 8512-4976)

Theoretical Considerations

The studies reported in Refs. 6–8 detailed the use of multiple regression procedures to generate simplified algebraic expressions relating building configuration parameters to the heating and cooling thermal load and/or energy use. Although various building models were used in each analysis, it was shown that a very convenient and compact equation form could be used to accurately predict load or energy. The equation presented below contains the major components contributing to building thermal

loads, namely: envelope conductance, solar gains, internal gains, and infiltration.

$$Q_{ij} = \alpha_i C_j + \beta_i S_j + \gamma_i L_j + \delta_i I_j \qquad (1)$$

where

$\alpha,\beta,\gamma,\delta$ = regression coefficients
C = envelope conductance
S = solar gain
L = internal gain
I = infiltration level
i = geographic location
j = configuration

The regression coefficients represent the climate dependent effect and also contain conversion factors to insure proper units. Each of the other terms is related to a particular configuration variable. This expression does not contain all load producing items; for example, natural ventilation could be an additional term. However, those items generally deemed necessary for adequate building energy analysis studies are included.

The convenient separation of variables provided by equation (1) permits an analysis of the influence of each component and also provides a method of showing under what conditions the (Q) values of two configurations are linearly related and climate independent. It is easily seen from the nature of this basic expression that the change in a component of (Q) is proportional to the change in a particular configuration variable. However, the linearity to be dealt with is the total heating or cooling load or energy, which can be expressed as:

$$\frac{(Q_{b2} - Q_{a2})}{(Q_{b1} - Q_{a1})} = \frac{(Q_{c2} - Q_{a2})}{(Q_{c1} - Q_{a1})} = \frac{(Q_{c2} - Q_{b2})}{(Q_{c1} - Q_{b1})} \qquad (2)$$

where a, b, and c refer to specific weather locations and 1 and 2 to different configurations. This form is used rather than a direct ratio, for example (Q_{b2}/Q_{b1}), since the intercept does not necessarily go through the origin. For equation (2) to be true, the variables α, β, γ, and δ must be related to a specific weather parameter (X_i) in the following fashion:

$$\phi_i = m_\phi X_i + k_\phi \qquad (3)$$

where (ϕ) represents the regression coefficient and (m) and (k) are slope and intercept values that define the functional dependence on the climate variable (X_i). This statement implies that each coefficient, or those which dominate, must be linearly related to the same weather parameter.

Such a condition is easily seen when one considers the heating requirement. For example, envelope conduction and infiltration, which are both temperature driven, are usually the largest components of the heating load; thus, heating degree hours can be representative of (X_i). Actually, the solar and internal gain terms also correlate with heating degree days, but not in as linear a fashion as the conduction and infiltration (see Ref. 6). The cooling load is somewhat more complicated than heating because of the influence of solar radiation and humidity as well as temperature. Reference 9 has shown, however, that the cooling load can be linearily related to cooling degree hours that are calculated considering not only outside air temperature but also humidity ratio.

Conclusions

a. The heating and cooling loads of one residential prototype appear to be linearily related to the loads of various prototypes regardless of geographic location provided levels of house conductivity, solar transmission, internal gains, and infiltration levels are not extremely different for each prototype. This is also true for the per unit floor area thermal loads.
b. Heating load/floor area correlates well with residential surface area to volume ratio. A unique characteristic curve relating these parameters can be defined as a function of prototype configuration properties and geographic location.
c. Percent heating load changes resulting from a conservation measure for a particular prototype also seem to be uniform throughout all climate locations. This implies, for example, that a 20% change in Chicago due to, say, wall insulation, would also be a 20% change in Phoenix.
d. Percent cooling changes due to conservation measures are not as uniform as heating changes throughout the climate range. However, the difference in values from location to location is not dramatic—on the order of a few percent.
e. Each prototype yields different percent distributions of the effect of a particular conservation measure. This conclusion is obvious when one considers the components contributing to a buildings thermal load.
f. Per unit floor area, the mid-townhouse yields the smallest heating load, followed by the end-townhouse, two-story, and split level. The ranch style house results in the largest heating load. The cooling load per unit floor area is lowest with the two-story, followed by the

split-level, ranch, and mid- and end-townhouses.

g. The slab-on-grade floor type, for a given prototype, results in the smallest heating and cooling loads when compared to the basement and crawl space floors. The basement yields the largest loads. However, if one considers the basement floor area in a per unit floor area comparison, basement prototype heating and cooling loads per unit floor area are the lowest.

h. A comparison of the thermal loads of many residential prototypes and configurations can be made based on the tabular load ratios. The documented linearities insure that the relationships defined will be quite accurate.

PLANNED ACTIVITIES FOR FY 1986

It is anticipated that the intra- and inter-prototype thermal load comparisons will continue through the next fiscal year. The results presented are representative of annual residential heating and cooling loads, but they do not relate to the individual incremental component loads which are of importance to decisions related to cost-benefit analysis. Additional analysis will be accomplished by investigating the thermal loads at the component level.

The results discussed have implications in regards to future parametric studies involving the thermal analysis of buildings. Understanding the characteristics of building parameters in varying geographic locations is greatly simplified through definition of a procedure utilizing the linearity reported. Such procedures will be defined and used on all subsequent studies.

Continued investigation of the theoretical considerations and specific definition of the weather variables, particularly those associated with cooling, that define the observed proportionality will continue to be analyzed.

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Federally-Assisted Housing: Plans and Preliminary Analysis*

R. Ritschard, C. Goldman,† E. Vine, R. Diamond,‡ E. Mills, and K. Greely

The potential for energy and cost savings in federally-assisted housing is great.[1] The financial, institutional, technical, and social barriers, however, are also tremendous. There is an indisputable need to reduce long-term energy costs through cost-effective retrofit measures. Investment in such options will maintain and improve the federal housing stock, will reduce energy consumption, will improve tenant comfort levels, and, most importantly, will save federal dollars.

In FY 1985, the Department of Energy initiated at LBL a research effort on federally assisted housing. The major emphasis was placed on publicly supported housing because of the availability of data and because a great conservation potential had been identified.[1,2]

Public housing authorities (PHAs) have begun in recent years to address their need to contain rising energy costs through various retrofit projects funded by the U.S. Department of Housing and Urban Development (HUD), by utility companies, or by the local housing authorities themselves using HUD operating funds. However, actual measured data on energy usage or data on the performance of energy saving measures are virtually nonexistent. Thus, many local PHAs are forced to make decisions about conservation investment strategies without a sound technical basis. The goal of this study is to characterize the existing public housing building stock and energy use patterns, to describe barriers to retrofit activity, and to conduct research that addresses these conservation barriers.

ACCOMPLISHMENTS DURING FY 1985

In FY 1985, we completed a major planning effort. The planning document[3] provides a profile of the existing data on energy use patterns and conservation in public housing. It also contains a description of the physical characteristics of existing buildings and the conservation potential. Finally, it identifies the various technical, informational, economic, behavioral, and institutional barriers that hinder the efforts of local housing authorities and HUD to promote energy conservation. Table 1 summarizes these barriers to conservation.

We also identified a set of research needs that can help overcome existing barriers to conservation in public housing (see Table 2). For each topic, we developed a brief research agenda for pursuit by DOE over the next few years. In addition, we suggest that improvements in existing information transfer mechanisms are needed to help eliminate certain barriers.

Table 1. Summary of barriers to conservation in public housing.

Technical
• Little technical analysis of retrofit actions already taken.
• Decisions made without adequate technical information.
• Conditions of housing may make retrofits impossible.
Informational
• Lack of knowledge about building stock.
• Lack of data on energy use pattens.
• No network for exchange of information.
• Availability and quality of information varies.
Economic, Behavioral and Institutional
• Tenants seldom included in retrofit process.
• No incentive for tenants to conserve energy.
• Cost-effective investments not always implemented.

Table 2. Summary of research needs in public housing.

• Detailed monitoring of retrofit performance.
• Analyze existing retrofit performance data.
• Characterize building stock and energy use trends.
• Evaluate financing and subsidy policy alternatives.
• Develop simplified audit and analysis methods.
• Analyze trends towards individual metering.
• Evaluate energy audits and audit procedures.
• Evaluate tenant incentive programs.
• Develop information dissemination strategies.

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†Buildings Energy Data Group of the Energy Efficient Buildings Program.

‡Energy Performance of Buildings Group of the Energy Efficient Buildings Program.

In FY 85, we initiated work on two of these research topics: retrofit performance monitoring and analysis of existing retrofit data. We also conducted a preliminary analysis of the impact of existing HUD funding policies on energy conservation activities of the San Francisco Housing Authority. (Presented as a separate Annual Report article.)

Retrofit Performance Monitoring

The objective of this research is to evaluate the installation and performance of a specific retrofit measure (e.g., solar hot water systems) in actual public housing buildings and to assess the effects of the retrofit on the building occupants. By March 1985, we had installed monitoring systems (i.e., data loggers) on four of the ten buildings at Holly Courts, a 118-unit public housing project in San Francisco. The data loggers have been collecting data on the temperatures and flows in the solar hot water system since that time. In addition, we interviewed members of 42 households about their hot water and energy consuming behavior. We present a more detailed account of the occupant behavior portion of this study in an accompanying Annual Report article ("Occupant Behavior in Public Housing").

Analysis of Existing Retrofit Data

Over the last decade, HUD and many local housing authorities have sponsored major retrofit projects in response to the "energy crisis," but little analysis has been performed to quantify the results. We initiated a project last year to evaluate systematically existing utility billing data on past and current retrofit activities at selected public housing sites in order to determine how effective these retrofits had been. In FY 85, we compiled data on 41 retrofit measures at 36 public housing projects. A more detailed description of this work is presented in an accompanying Annual Report article ("Measured Energy Savings From Conservation Retrofits in Public Housing Projects").

PLANNED ACTIVITIES FOR FY 1986

In FY 1986, we will continue the retrofit performance monitoring at one of the Holly Courts buildings and complete the analysis of existing retrofit data. We will also initiate a baseline energy use analysis.

Retrofit Performance Monitoring

We will complete the analysis of energy use, hot water demand patterns, and solar system performance, and conduct a follow-on tenant survey. At the end of FY 1986, we plan to have a better understanding of the variation in performance of the retrofits and variation in domestic hot water usage in the overall context of a whole-building system. We also expect to determine whether the results of this case study can be extended to other buildings, including public housing projects in San Francisco and in other parts of the country and to multi-family buildings in general.

Analysis of Existing Retrofit Data

We will complete the analysis of 41 retrofit measures and prepare a final report that will be circulated to DOE, HUD, and local housing authorities for their review. In addition, we will gather additional data, if available, in areas that are currently not included, such as projects that have implemented shell measures and projects in the South and Midwest, etc. The results of this analysis will provide cost/savings estimates for various retrofit measures that can be compared to similar results from the private sector. The findings should also be useful to HUD's conservation programs by providing some information on what retrofit measures from our sample worked.

Baseline Energy Use Analysis

Our literature search and survey of local housing authorities led to the conclusion that an analysis of baseline energy use data from selected multi-family buildings is needed. This effort includes collecting data on building characteristics and energy use, analyzing the energy use data to adjust for weather and occupant effects, and estimating the influence of building and operating conditions on variations in energy consumption. The results of this analysis can provide useful information in support of developing simplified energy analysis methods for multi-family housing. This research addresses the apparent lack of accurate energy use estimates for multi-family units in both the private and public sectors. The baseline analysis will also be of particular interest to HUD policymakers, who could use the results to estimate Allowable Utility Expense Levels for local PHAs and Utility Allowances for the public housing tenants.

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Measured Energy Savings from Conservation Retrofits in Public Housing Projects*

C. Goldman,† K. Greely,† and R. Ritschard

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 major retrofit activity, little documented information is available on the energy savings from retrofits.[1] This article, which summarizes a more detailed LBL report,[2] describes a project that is part of DOE's long-term program to improve energy efficiency in federally-assisted housing. The objectives of this project are: 1) summarize measured data available on previous HUD conservation initiatives, 2) develop a consistent analytic framework to use in determining energy savings and cost-effectiveness of conservation retrofits, 3) discuss factors that are correlated with high or low energy savings, and 4) provide recommendations on cost-effective retrofit strategies based on measured data.

In this article, we describe sources for retrofit data in public housing and discuss problems encountered during the data compilation process. In addition, we outline the methods that we will use in FY 86 to determine energy savings and cost-effectiveness. We also discuss preliminary results from projects with sufficient data, including distribution of retrofit costs, frequency of specific types of measures, and the physical and demographic characteristics of the included projects.

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

†Buildings Energy Data Group of the Energy Efficient Buildings Program.

ACCOMPLISHMENTS DURING FY 1985

We obtained information on retrofit projects from PHAs, HUD regional offices, and consultants who worked for local PHAs. The data collected typically included metered energy consumption, installed retrofit measures and their cost, the price of the space heating fuel the winter after retrofit, and a brief description of the physical characteristics of the buildings (e.g., conditioned floor area, building and heating system types). We designed a database management system that stores information on project building characteristics and historical energy use and that includes data fields that specifically interface with reporting forms filed with HUD by local public housing authorities (HUD-51466B and HUD-51885).

In 1980, HUD awarded $23 million to 47 PHAs for modernizing oil heating systems and another $5 million to 61 PHAs to install and test innovative energy conservation and solar measures. Comprehensive evaluations were available from only three of 61 PHAs (Trenton, NJ, Greeneville, TN, and St. Paul, MN)[3–5] that participated in the innovative energy grants program. We contacted the Office of Public Housing in HUD for information on the results of retrofit efforts in 14 other PHAs that had received grants. HUD responded that eight of these 14 had not reported any results and that one PHA had never carried out the retrofit and provided LBL with brief progress reports from the remaining five PHAs. Ironically, as of February 1985, two of the five PHAs that submitted progress reports did not include energy use data because of delays in installing the retrofits; hence savings from the retrofits are still not known. Our experience with innovative energy grant recipients illustrates some of the difficulties in obtaining measured data on the results of conservation activities. Moreover, it indicates that, except for a few PHAs, a serious evaluation has not been conducted of HUD's early conservation initiatives.

LBL has also contacted many local PHAs directly in an effort to determine the scope of their

recent retrofit activity, to discover whether evaluations of previous efforts had taken place, and to learn of their plans for future retrofits. The response to this mail survey was particularly encouraging (29 large PHAs, or nearly 40%, returned completed questionnaires). Over the last year, we contacted 10 other PHAs through telephone surveys. From this group, we have received information on building stock characteristics, heating system specifications, fuel types, and maintenance problems in addition to energy retrofit activities. The survey indicates that various retrofits had already been implemented at nearly all PHAs surveyed. Conservation measures/practices include boiler plant modernization, hot water flow restrictors, "shell" weatherization measures (weatherstripping/caulking, insulation, and window replacements), tenant education, meter conversions, lighting retrofits, and solar systems installation. With few exceptions, PHAs have conducted only preliminary analyses of the effectiveness of these measures; typically, LBL still must perform the energy and economic analysis. The survey has so far yielded usable data on 25 projects—14 projects managed by the New York City Housing Authority and 11 projects operated by the San Francisco Housing Authority.

Results

At present, we have compiled data on 36 housing projects that have installed retrofits. The overwhelming majority of projects are centrally heated (89%), and most heat with oil (54%), followed by natural gas (37%). Of the projects with central heating systems, 31% heat with hot water while 38% have steam distribution systems. Roughly half of the projects are low-rise buildings (4 stories or fewer) while 47% are high-rise complexes (Fig. 1). Families occupy 58% of the housing projects, while 22% contain senior units. Almost all projects are master-metered, which typically means that tenants do not pay their space heating and hot water costs directly. There is a large variation in the number of units in each project, ranging from a project with single-family dwellings to 1000-unit apartment complexes with several buildings. Our sample has a distinct regional bias, as the buildings are concentrated principally in the New York–New Jersey area and California. To some extent, this bias replicates the concentration of public housing units in the Northeast corridor. Retrofit data are needed for the Midwest and South, however.

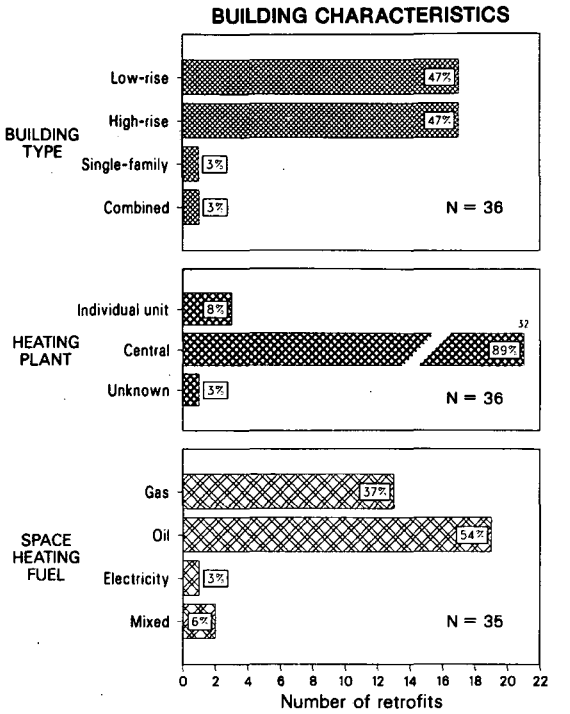

Figure 1. Selected characteristics of projects in the database. Note the bias towards centrally-heated, oil-fueled buildings. (XCG 858-382)

Conservation Strategies

Most retrofits are directed towards improving energy efficiency in the two largest end use areas (measured as a percentage of site energy consumption): space heating and domestic hot water. Figure 2 is a histogram of the frequency with which various retrofit measures were installed in the 36 projects. In most cases, more than one measure was installed at each project. The median first cost is approximately $550/unit for the 38 projects. Many authorities confined their retrofit efforts to low-cost measures. For example, retrofitting existing heating systems with improved controls was the most common measure, with first costs ranging from $100–450/unit. Examples of retrofits included in this category are thermostatic radiator vents, boiler aquastats, outdoor resets, and cutouts. Retrofits to reduce domestic hot water use were also frequently implemented. The San Francisco Housing Authority installed solar domestic hot water systems at six projects, and wrapped hot water tanks at two other pro-

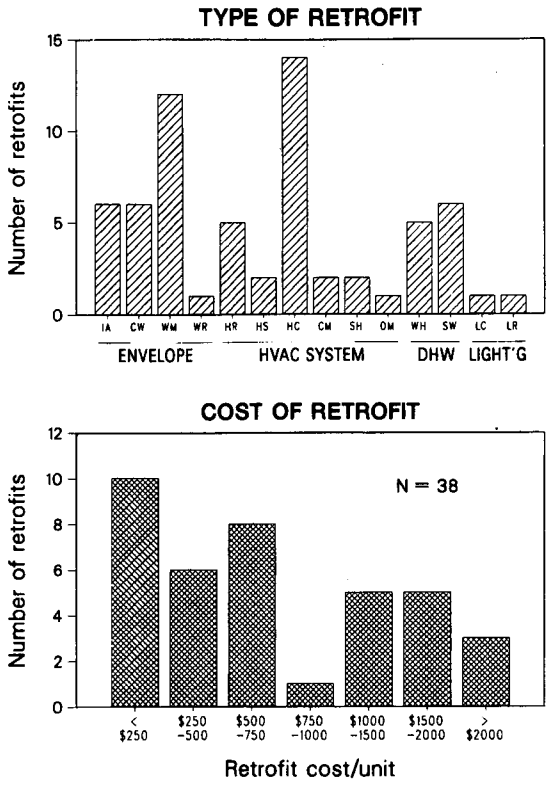

Figure 2. Retrofit characteristics. "Type of Measures" refers to measures implemented singly or in combination with other retrofits. Therefore, the number of retrofits shown here is greater than the number of analyzed retrofits. "Cost of Retrofits" is the initial cost, in 1985 dollars. Retrofit Codes: AI = Attic Insulation, CW = Caulk & Weatherstrip, WM = Window Measures, WR = Window Replacement, HR = Heating System Controls, CM = Computerized Heating Control System, SH = Solar Space Heat, OM = Operations and Maintenance, WH = Water Heater, SW = Solar Domestic Hot Water, LC = Lighting Controls, LR = Lighting Replacement. (XCG 858-380)

jects, while several Northeast housing authorities installed separate domestic hot water boilers. Window measures were also extremely popular. For example, the New York City Housing Authority installed double-glazed thermal-break aluminum windows in nine apartment complexes. This retrofit was fairly expensive, averaging $1070/unit in the nine buildings. Several local authorities indicated that window retrofits were favored by tenants because of their high visibility, i.e., they tend to improve building appearance and security. Several of the retrofit strategies, e.g. the solar retrofits, had particularly high initial capital costs; hence, at these projects, we will be taking a close look at cost-effectiveness as well as the energy savings levels, particularly given that existing tax credits (which will soon expire) improve the attractiveness of these investments.

Conclusion

During FY 85, we gained first-hand experience with problems that make it difficult to determine energy savings attributable to conservation measures. These include: 1) absence of good record-keeping, 2) limited contact between local public housing authorities and the buildings research community, and 3) little awareness of the potential benefits to the PHA of evaluation. We hope this study, when completed, will at a minimum summarize measured data on retrofit efforts in public housing. Optimally, it will provide recommendations on what conservation measures work best for specific building and heating system types. In addition, we hope the database management system and analytic methods that we are utilizing will serve as an example to HUD and local public housing authorities of the feasibility and importance of developing an energy management accounting system that incorporates historical energy use and occupancy, weather, key building characteristics, and economic data in order to track energy use patterns and determine energy savings and cost-effectiveness.

PLANNED ACTIVITIES FOR FY 1986

In FY 86, we will obtain and report results from the energy and economic analyses and target further data collection efforts in areas that are currently under-represented. We will focus on data collection in the following areas:

- projects located in the South and Midwest,
- projects that have implemented shell measures (e.g., attic and wall insulation, infiltration-reduction),
- retrofit efforts in buildings with individual apartment heating units or that heat with gas or electricity.

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Impact of HUD Subsidy Policy on Retrofit Savings for Public Housing Authorities*

E. Mills and R. Ritschard

The cost-effectiveness of energy conservation retrofits in the public housing sector must be viewed from a special financial perspective. Rather than attributing costs and benefits to a single party, it is necessary to determine cost-effectiveness for two actors—the U.S. Department of Housing and Urban Development (HUD) and the public housing authority (PHA). Our calculations show that actual savings can be negative for the housing authority, even for retrofits with very short payback periods according to the single party model. The exact distribution of benefits is determined by the HUD subsidy framework—the Performance Funding System (PFS). Under the PFS, the housing authority retains roughly one and one-half years of utility expense savings over the life of the retrofit. Key policy questions center around the influence such a sharing of savings may have on the choice made at the housing authority level of whether to invest in conservation, and if an expanding "pie" could be enjoyed by all actors under an alternative allocation of costs and benefits.

This work is a follow-on to our analysis of energy savings using actual pre- and post-retrofit PHA utility data normalized to long-term average weather conditions. The financial results discussed here differ significantly from ones based on the simple payback time and presented in a previous report.[1]

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

ACCOMPLISHMENTS DURING FY 1985

Modeling the PFS

We developed a micro-computer spreadsheet to model the allocation of costs and benefits of retrofit activity between HUD and the PHA, based on the subsidy system rules. The subsidy for PHA utility expenditures, known as the "Allowable Utility Expense Level," is the product of expected consumption and price for each fuel. Consumption is estimated by calculating an average based on three previous years of utility billing data. This estimate is reviewed at year-end and compared to the actual energy use levels. HUD recaptures any savings resulting from lower than expected *prices* or reimburses the PHA for additional energy expenditures resulting from price increases. More importantly, if *consumption* changes, HUD and the PHA share the difference between estimated and actual consumption on a 50/50 basis. As a result, during the years following the installation of a retrofit the subsidy decreases along with the rolling base. By year six the subsidy is completely adjusted; i.e., HUD recaptures all of the energy savings. The PHA retains roughly one and one-half years of the lifetime energy savings. Table 1 illustrates the year-by-year distribution of retrofit energy savings.

The ultimate distribution of energy savings also depends on how the retrofit and associated maintenance costs are paid for. Energy improvements are ordinarily capitalized with HUD Modernization Funds. In rare cases, a housing authority will pay for the retrofit with general operating subsidies (intended for non-energy applications) or will con-

Table 1. Annual distribution of HUD/PHA energy savings under the Performance Funding System. We assume that the retrofit is installed in the middle of year one.

Year	PHA % share	HUD % share
0	—	—
1	25.0	25.0
2	50.0	50.0
3	33.5	66.5
4	16.5	83.5
5	0.0	100.0

tract with an Energy Service Company (ESCO) to finance the project. Many retrofits also have substantial associated maintenance costs or savings, for which the housing authority is not compensated.

Methodology

Using the PFS treatment of savings and costs, we can determine the net present values (NPVs) of costs and savings, over the life of a retrofit, for HUD and the PHA. We begin with *measured* energy savings, from analysis of housing authority monthly utility bills, and normalize consumption for differences in weather conditions and, when possible, changes in occupancy before and after the retrofit. We use local energy prices, reported by the PHA, to compute the dollar savings in year one and apply DOE residential price escalation forecasts to estimate the effect of future price changes.[2] We then distribute the annual savings between HUD and the PHA according to the factors developed in Table I. The retrofit cost is deducted from the present value of HUD's energy savings if the retrofits are paid for by HUD under its Modernization program and from the housing authority savings if the PHA pays for the retrofit out of general operating subsidies. The present value of any associated maintenance costs, over the retrofit lifetime, is deducted from the PHA's energy savings.

Case Studies

We completed an analysis of the impact of the PFS on a retrofit project undertaken in 1982 by the San Francisco Housing Authority (SFHA). The Authority insulated and weatherized a number of multi-family, low-rise buildings utilizing a zero-interest loan program available through their local utility. We analyzed utility bills for 1827 dwelling units distributed in five projects and calculated gas savings from three years of utility bills, two years before and one year after the retrofit. The simple payback time for the measures was 2.2 years, under the assumption that one party finances the retrofit and retains the savings. However, the PFS methodology shows that the actual net present value of the retrofit savings and costs is −$78,600 (−$43/dwelling unit) for the Authority and $1,426,900 ($781/dwelling unit) for HUD.

The negative savings occurred because the San Francisco Housing Authority capitalized the retrofit with their general operating subsidies rather than Modernization Funds intended for conservation investments. Although the PHA obtained a zero-interest loan, the present value of eight years of payments exceeded that of their energy savings. Figure 1 illustrates the resulting distribution of gas savings between HUD and the PHA and the relative size of the loan annuity.

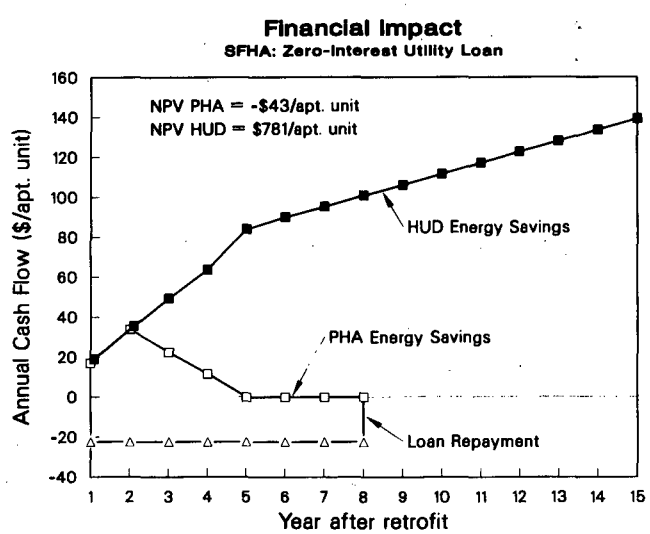

Figure 1. Allocation of energy and cost savings from a retrofit package that includes attic insulation, water heater retrofits, caulking/weatherstripping, thermostat clocks, and heating controls under the Performance Funding System. The present value of the loan payments is subtracted from the PHA energy savings in the net present value (NPV) calculation because the funds are diverted from general operating subsidies. (XCG 865-7232A)

Conclusions

Given the characteristics of the Performance Funding System, cost evaluation methods such as the simple payback time can not capture the differences in benefits for HUD and the PHA. Energy savings may be insufficient to balance capital costs paid by the authority. The project we analyzed had a simple payback time of only 2.2 years, and yet produced *negative* savings for the PHA and substantial positive savings for HUD because the authority paid for retrofits with general operating subsidies. Following is a list of preliminary findings derived from the case study and from examination of the subsidy system rules.

- A one and one-half year payback time is required if the PHA finances the retrofit out of general operating subsidies.
- Negative savings can result for the authority if the retrofit requires new maintenance expenditures for which the authority receives no subsidy supplement.
- An authority has little or no incentive to insure that savings persist beyond year five. It may in fact be profitable for them to let maintenance programs lapse once HUD has recaptured the yearly energy savings.
- If a retrofit fails to save energy, savings degrade with time, or savings are negative, HUD experiences a greater loss than the PHA.
- It is difficult for the PHA to contract with private sector energy service companies (who are normally compensated from the energy savings) because HUD recaptures most of the savings.

PLANNED ACTIVITIES FOR FY 1986

Our next step is to develop the model further to reflect various innovative conservation investment strategies. We will develop prototypical spreadsheets, using LOTUS 1-2-3, to represent these strategies and compare their relative financial impacts. The spreadsheets will be useful to PHAs interested in planning future retrofit projects and evaluating previous ones. They will assist policymakers in analyzing the quantitative impact of alternative utility subsidy options.

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Analysis of Occupant Behavior and Energy and Hot Water Consumption in Public Housing*

E. Vine and R. Diamond

Lawrence Berkeley Laboratory has been involved in the analysis of energy-related issues in public housing since the early 1980s. The principal objective of this research has been to understand how energy is used in public housing by analyzing baseline energy use, energy conservation retrofits, and tenant behavior. In the past year, the Energy Analysis Program and the Energy Performance of Buildings Group (of the Energy Efficient Buildings Program) focused their research on tenant behavior as part of a research project that was monitoring the performance of a domestic hot water retrofit at a public housing project in San Francisco (see the other Building Energy Analysis articles in this report).

ACCOMPLISHMENTS DURING FY 1985

A key activity of DOE's Building Energy Retrofit Research project is to improve the energy efficiency of the nation's public housing stock. During the past year, a research plan was drawn up that identified short-term research needed to meet this ambitious and important goal.[2] One of the research areas identified in the plan was the need to conduct retrofit performance monitoring. The purpose of the retrofit monitoring is to evaluate the installation and perfor-

*This work was supported by the Assistant Secretary for Conservation and Renewable Energy, Office of Buildings and Community Systems, Systems Analysis Division of the U.S. Department of Energy under contract DE-AC03-76SF00098.

mance of specific retrofits, and to assess the effects of the building occupants. Our review of energy conservation work in public housing also indicates that, in spite of major retrofit activity, little effort had been made to evaluate the effect of such activity. Previous evaluations relied almost exclusively on whole-building utility billing data or on engineering estimates.[3] These data do not permit analysis of the significant factors that affect retrofit performance, nor can they explain differences between predicted and actual energy savings. Detailed monitoring of public housing buildings, however, allows us to characterize the energy savings more fully, evaluating the installation and performance of the retrofits, as well as the effect of building occupants.

In October 1984, we began a hot water retrofit monitoring project in conjunction with the Housing Authority of San Francisco. The housing project selected for this study was Holly Courts. The goal of the project was to evaluate the performance of a solar domestic hot water retrofit, looking not only at the performance of the system (the supply side), but also at the hot water usage patterns of the residents (the demand side). This is one of the first detailed evaluations of a hot water retrofit in a multifamily building; the results will thus have important applications for sectors besides the public housing stock.

Holly Courts, California's first public housing project (1939), is located in south-central San Francisco. While the climate can be cool and foggy at anytime of year, the sun shines on an average of 66% of the daylight hours. San Francisco has 3080 annual heating degree days (base 65°F) and 39 cooling degree days (base 65°F). Half of the units have a southern exposure. The 118 apartments are located in ten two-story, bungalow-style buildings, and the project has 48 one-bedroom units, 60 two-bedroom, and 10 three-bedroom units, housing over 350 residents. The average apartment size is 794 ft^2. The buildings have concrete construction and originally were uninsulated. However, blown-in insulation (R-19) was installed between the roof deck and the second story ceiling in September, 1982. The original wood casement windows were replaced in the early seventies with single-pane aluminum-frame windows. The apartments are individually heated with a free-standing gas heater; domestic hot water is provided by gas-fired central boilers in each building. The tenants are billed directly for their gas usage (for space heating and cooking) and for electricity. The Housing Authority pays for the gas for the domestic hot water. The average energy consumption per unit in 1984–85 was 210 kWh per month for electricity, and 21 therms per month for gas. Average monthly domestic hot water gas consumption per unit is about 32 therms, larger than the gas use for space heating.

The retrofit to the domestic hot water system involved installing a total of ninety-four 4 ft × 10 ft solar collector panels on the roofs of the ten buildings. The solar collectors were plumbed into storage tanks located in the boiler rooms in the basements of the buildings. The solar storage tanks were connected into the existing domestic hot water system for the building. Installation began in November, 1984, and by January, 1985, the solar systems were operational in all ten buildings. By March, 1985, the first of our monitoring systems were installed in the boiler room in one of the buildings at Holly Courts. In the next few months, we installed three additional data loggers in different buildings. We installed a weather station on the roof of one of the buildings to collect local temperature, wind, and solar data.

The data acquisition system was a flexible, programmable, modular system that operates unattended in the boiler rooms at Holly Courts. Real time data for site weather conditions, individual building domestic hot water use, and the contribution of the solar system were collected and converted to hourly averages. Data were stored in the system's memory and were transferred weekly to LBL by a phone modem. We calculated the following quantities from the monitoring: quantity of hot water used, temperature of hot water delivered to occupants, heat loss in building hot water pumped loop, temperature of cold and solar preheat water supply, and operation time and average collection efficiency of the solar system.

Table 1 shows the domestic hot water consumption for the individual buildings from April to July, 1985.

The average household consumption, 88 gallons/day, appears to be higher than any of the average values given in the literature. In the coming

Table 1. Holly Courts hot water consumption.

Bldg.	Units	People[a]	Gal/day[b]	Gal/unit/day
D	9	19	755	84
E	15	35	1346	90
F	15	46	1447	96
G	9	21	678	75
TOTAL	48	121	4226	88

[a]Estimated from 87% of units surveyed.

[b]Average from 4/85–7/85.

year, we plan to examine the literature in greater detail to compare our domestic hot water usage pattern with those reported in other studies.

We conducted a survey of the occupants of Holly Courts in order to obtain information to:

1. describe daily domestic hot water use profiles,
2. examine how hot water use profiles affect the performance of the solar system,
3. examine how the solar hot water retrofit affects hot water use profiles,
4. compare occupant-reported hot water usage with actual hot water usage,
5. compare hot water use and energy consumption.

We conducted the survey in May of 1985, five months after the solar retrofits were installed. We completed interviews at 42 of the 48 units (88% response rate) in the four buildings being monitored. The interviews, conducted in English and Spanish, took approximately 20 minutes each. We asked residents about their daily hot water use in the bathroom and kitchen, their satisfaction with their hot water, their awareness of the solar system, their attitudes towards conservation, and standard demographic variables.

Respondents in our survey were typically not married, female, about 45 years old, and had less than high school education (Tables 2 and 3). Almost 40% of the sample was black, 32% were white, and 25% Hispanic. Over one-half the sample were unemployed or retired with only 12% working full-time, typically in a service occupation. In general, the population was stable with relatively little turnover in household composition from the previous year and with relatively long tenancy in the public housing complex.

Table 2. Holly Courts occupant profile.

	Avg.	S.D.[a]	Range	No.
Number of years lived in Holly Courts	9.5	6.7	1–28	42
Number of years lived in same apt.	8.2	6.6	1–23	42
Age of respondent (years)	45.5	16.7	21–82	40
Education of tenant (years)	10.6	4.0	0–17	40
Avg. household size (people)	2.6	1.6	1–9	42

[a]S.D. = standard deviation.

Table 3. Holly Courts frequencies.

Sex of respondent (N = 42)	7.1%	Male
	92.9%	Female
Ethnicity of respondent (N = 41)	4.9%	Asian American
	39.0%	Black
	31.7%	Caucasian
	24.4%	Hispanic
Marital status of respondent (N = 42)	40.5%	Single
	7.1%	Married
	28.6%	Separated
	23.8%	Other
Employment status of respondent (N = 41)	12.2%	Working full time
	22.2%	Working part time
	14.6%	Retired
	48.8%	Unemployed
Occupational status of respondent (N = 11)	18.2%	Professional
	9.1%	Craft
	72.7%	Service
Changes in the number of people occupying a unit in the last year (N = 39)	25.6%	Yes
	74.4%	No

Hot water consumption varies greatly over a daily cycle. A typical daily profile shows peaks in the morning and evening indicating family bathing practices, peaks around meal times for cooking and dish washing, and scattered peaks throughout the day for clothes washing. For example, the average daily hot water consumption for a one week period in Building D, a nine-unit building, varied between 30 and 40 gallons per hour, with peak rates exceeding 150 gallons per hour.

We used the survey data to reconstruct the end use breakdown for the daily profiles by combining their reported frequency of use with standard usage factors. The largest daily hot water use (43% of total) was for bathing and showering, which was split evenly between the morning and evening periods. Clothes washing was the next largest user (30%), and occurred during the morning, afternoon, and evening periods, with the greatest usage in the morning. The third main hot water use was for dish washing (26%), and followed the same pattern as clothes washing.

We combined the reported data on time and frequency of hot water use to form an average daily

profile, which was compared to the measured average daily profile (Fig. 1). (We added the average measured nighttime flow to the reported data to account for leaking faucets.) The profiles are remarkably close, giving support to the reliability of the occupant reported data. Interestingly, the profiles in no way resembled the standard profile for average daily consumption reported in the literature and widely used for calculating collector sizes, and estimating performance of retrofits.

Not only are the usage patterns at Holly Courts unusual, but the absolute water consumption is higher than usual. This raises the question of whether this is an anomaly, or whether the results can be extended to other buildings, including other public housing projects in San Francisco and elsewhere, and to multifamily buildings in general.

PLANNED ACTIVITIES FOR FY 1986

Our findings so far indicate that evaluation of retrofits is difficult and that even such straightforward questions as energy savings and costs are hidden by a complex interaction of physical, institutional, and behavioral issues. While we have a better understanding of the whole system, there are still important questions to answer, including the following:

1. What is the variation (seasonal, weekly, weekday/weekend, daily) in performance of retrofits?
2. What is the variation (seasonal, weekly, weekday/weekend, daily) in domestic hot water usage?
3. How does domestic hot water usage compare with energy consumption?
4. What are the sociodemographic differences between high and low water consumers?
5. Why do Holly Courts' daily profiles differ from those reported in the literature?
6. How can we explain differences in water usage between different buildings—e.g., different boilers, circulation losses, etc?
7. How does occupant-reported behavior compare with actual usage?
8. What additional retrofits would be appropriate and cost-effective for these buildings?
9. How generalizable are the results from this study to other public housing and multifamily housing projects (in San Francisco and elsewhere)?

We hope to derive answers to these questions from analysis of data we have collected, and other existing data, literature reviews, and, possibly, another survey of Holly Courts.

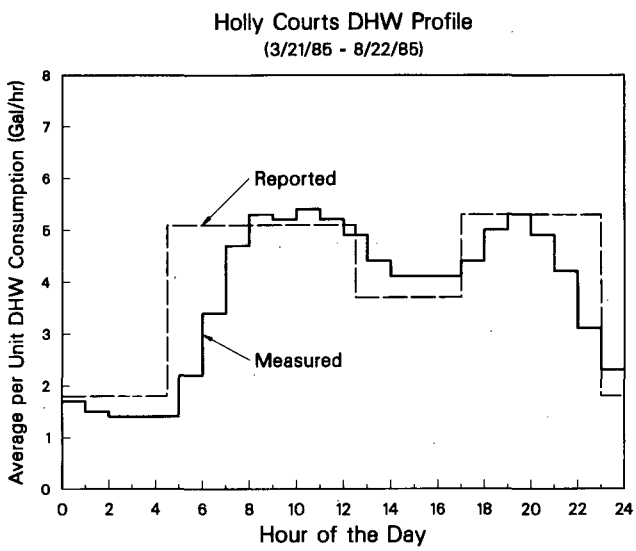

Figure 1. Comparison of reported and measured domestic hot water consumption by time-of-day. (XCG 8512-552)

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Home Energy Rating Tool: Follow-On Analysis*

R. Ritschard, C. Hsui, and Y.J. Huang

During FY 1984, we initiated an effort for the California Energy Commission (CEC) to develop a simplified energy rating tool for existing houses as part of a Home Rating and Labeling Demonstration Project. The major goals of this work are: (1) to develop and field-test a simple and reliable tool for estimating the energy efficiency of typical existing homes and to assign ratings to them, and (2) to explore various delivery mechanisms for promoting the use of the rating tool. The CEC selected three areas of the state to test three delivery mechanisms. The City of Roseville will implement a program in which the city, as an electric utility, will offer the home rating and labeling service. As the model for a utility-focused delivery mechanism, Roseville will conduct a certified audit of homes and deliver the appropriate rating label. The City of Pasadena will operate a program very similar to that of Roseville but, as the model for the government-focused delivery mechanism, will use city building officials to certify a home's rating and provide labels. Finally, the County of Marin will test the rating program through realtors. Trained realtors operating within the county will market the rating and labeling service and, with some assistance from the county, provide audits and labels on their own.

The follow-on work described here illustrates the feasibility of translating complex technical information, which result from a series of parametric simulations using a state-of-the-art computer code (DOE-2.1), into a simplified format ("slide rule") that can be used by a non-technical audience. If the rating tool in combination with the delivery mechanisms being tested should prove successful, it may have applicability to other areas in California as well as to other parts of the country.

ACCOMPLISHMENTS DURING FY 1985

During FY 1985, we completed a final version of the home energy rating tool for each of three California climate zones: Zone 3 (Marin), Zone 9 (Pasadena), and Zone 12 (Roseville). All values used in the rating tool, with the exception of those for domestic hot water, are based on DOE-2.1A simulations. (Test runs with DOE-2.1B showed insignificant differences in total loads.) The domestic hot water values used on the rating tool are calculated using standard CEC procedures. During the first part of the analysis, we compared consecutive DOE-2 runs to determine the Δ heating and cooling loads for each conservation measure (e.g., R-30 ceiling compared to R-19 ceiling, etc.) while holding other parameters constant. We performed these DOE-2 simulations on the one-story and two-story prototypes for various thermal integrities (ceiling, wall and floor insulation, different infiltration levels) and window measures (i.e., window area, number of panes, type of window sash, shaded and unshaded) in the three climate zones.

After developing a database of Δ heating and cooling loads, we regressed these Δ loads against Δ steady-state conductances to calculate the component loads for each individual building component. We used this analytical approach to develop an energy calculating slide rule for new site-built, single-family houses in support of a Department of Energy program.[1] In our previous work, we showed that this method is reliable and allows one to recompose DOE-2 energy budgets for any particular combination of conservation measures within the database to a high degree of accuracy (within 8% for heating and 12% for cooling). We describe the methodology in greater detail elsewhere.[2] These component loads, with a few minor modifications, are converted into heating and cooling normalized units, which appear on the rating tool.

Figure 1 shows the draft rating tool for climate zone 3. To use the rating tool, one follows a series of sequential steps indicated by the heavy lines on the rating tool sleeve. First, the user aligns each of the six tabs (A-F_N) to the appropriate level of conservation for the ceiling, walls, floor, infiltration, window area (including total south window area), window sash type, glazing levels (i.e., single-, double-, or triple-pane), and presence or absence of thermal mass. The thermal mass side of Tabs E and F (i.e., E_M and F_M) are used only for houses where over half of the floor area (or an equivalent amount of wall area) has exposed concrete or tile that is in the path of direct sunlight. Tabs A_1 through D_1 are used for one-story houses, while the reverse sides of each tab, which are labeled A_2, etc., are used for two-story buildings.

The user computes an energy rating by adding the numbers for both heating and cooling that appear in the small windows to the left of the six

*This work was funded by the California Energy Commission under Contract No. 400-83-009, with facilities support provided by the U.S. Department of Energy under Contract No. DE-AC03-76SF00098.

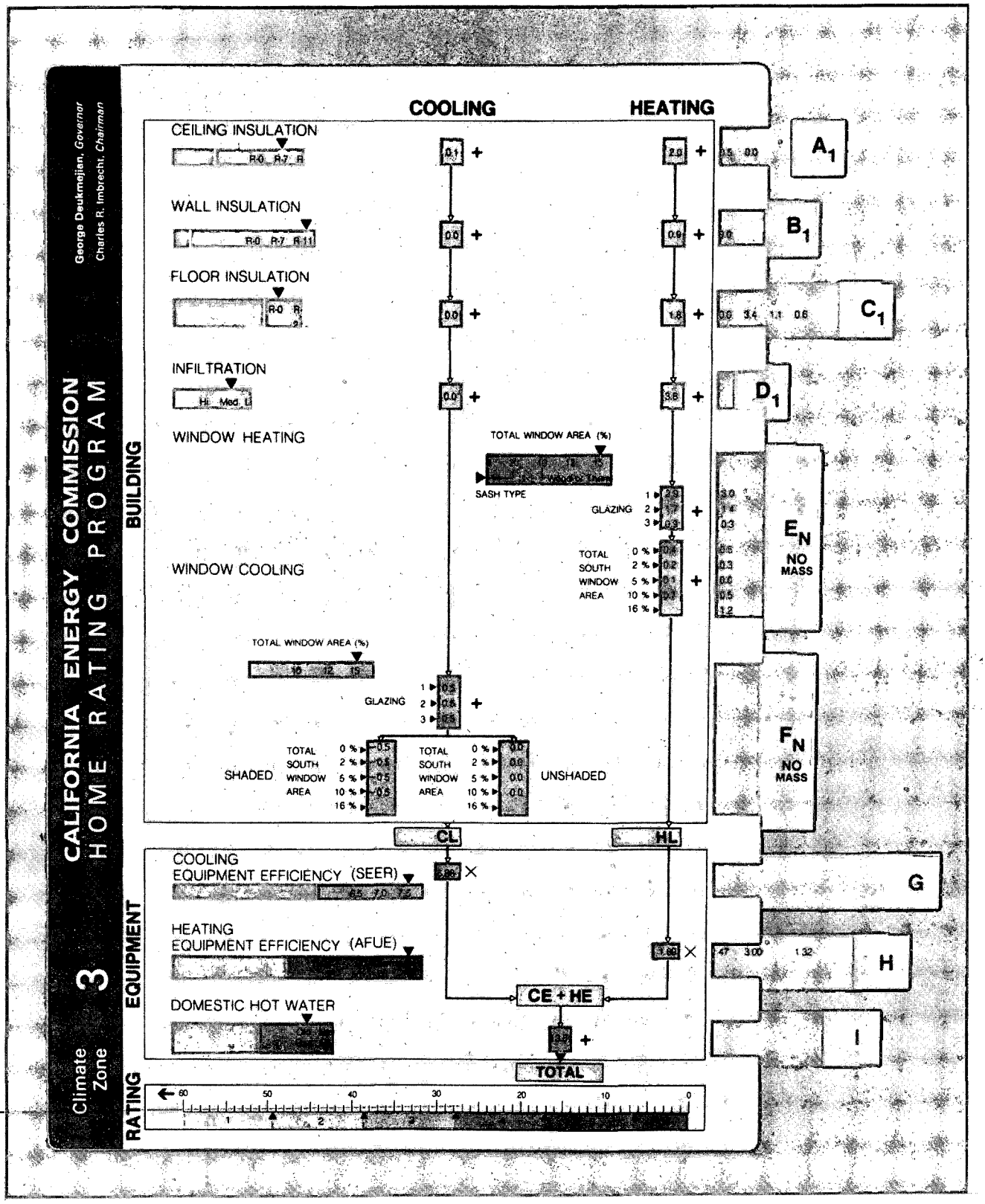

Figure 1. Draft rating tool for climate Zone 3. (CBB 8512-10177)

tabs. The sum of these values represents the heating and cooling load of the house. One then converts the loads into energies by multiplying them by the appropriate heating and cooling equipment efficiencies from windows adjacent to Tabs G and H. Finally, the domestic hot water system (including solar) is considered on Tab I, and the calculated value is added to the heating and cooling energy use to produce a final house energy usage (in the Total window). The user can then get credit for additional energy conservation features, such as setback thermostats, low-flow shower heads, and outlet gaskets, by subtracting the estimated savings (available on a supplemental form) from the total energy use calculated on the rating tool. This final value is converted into a energy rating scale on the tool that ranges from 1 (poorest) to 6 (best). The scale was set using the energy budget for a house that met the 1978 new building standard as a "3," and a current Title 24 house (1982 new building standard) as a "5." All rating are scaled linearly from these two benchmarks. Because of the differences in their climates, there are different rating tools for each demonstration city.

Due to printing delays at the CEC, the demonstration period did not begin until the end of FY 1985. At that time, the County of Marin withdrew its participation in the program because of an unwillingness on the part of the realtors to assume responsibility for rating properties that they would later market. The demonstration phase, however, will continue in the other two communities during most of 1986, and a follow-on evaluation program will be initiated.

PLANNED ACTIVITIES FOR FY 1986

In FY 1986, we will prepare a report that documents the technical assumptions and methodology used to develop the rating tools for the three demonstration areas. In that report, we will describe the prototype buildings and modeling assumptions used in the computer simulations and compare them to the analysis used to generate the California Title 24 budgets. Next fiscal year, we will also extend our analysis to the other 13 California climate zones. We will complete our analysis of all 16 climate zones using DOE-2.1C, the most up-to-date version of the program, which will then be available. We anticipate that after the demonstration period has been completed, we will make modifications to the rating tool format, if necessary, and produce a complete set of rating tools for all of the climate zones.

An important aspect of the CEC Program is to evaluate the process of rating and labeling houses. Next year we will determine the effectiveness of the delivery mechanisms used during the demonstration projects in the Cities of Pasadena and Roseville. The goal of this evaluation is to determine the usefulness of the home rating system to homeowners, lenders, project proponents, and others in the building industry. To meet the goals of the process evaluation, we plan to:

1. Identify and recommend solutions to technical and delivery problems identified during the demonstration phase.
2. Review, on-site, a sample of labeling conducted by each pilot demonstration city.
3. Identify any additional training that may be required and the specific target audience (i.e., local government staff, local utility staff, etc.).
4. Compare delivery mechanisms utilized in CEC demonstration projects and identify strengths and weaknesses of each approach.
5. Identify other potential users and uses for the home rating system.

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Performance of Daylighting Systems in Commercial Buildings in Hot Climates: Singapore Case Study*

M. Levine and I. Turiel

The term daylighting encompasses various strategies for using light from outside a building to replace artificial interior lighting. It is potentially a powerful way to reduce building energy use in hot, sunny locations.[1] Although modern interest in daylighting is now almost ten years old, it has not been extensively applied.[2] This lack of implementation persists in spite of the substantial potential benefits from reduced energy use and equipment costs that are possible, especially in commercial buildings.

Often architects are not familiar with the concept of daylighting, and even when they are aware of its advantages, methods of evaluating the benefits of various daylighting configurations are not widely available and are complex.[3] Consequently, choosing an optimal daylighting strategy is beyond the reach of most practicing building designers.

The long run objective of this research is to develop a tool that can promote wider use of daylighting in commercial buildings at a specific location, Singapore. This tool should simplify the task of choosing an optimal daylighting strategy by permitting building designers to estimate and compare the potential reductions in energy use that would result from various daylighting approaches. Later the algorithm will be incorporated in a microcomputer program and made available to Singapore's architects and building engineers.

ACCOMPLISHMENTS DURING FY 1985

Methodology

Our general approach is to model the effects of daylighting in a reference Singapore office building and then use physical understanding to generalize the results obtained from a small set of simulation runs. We began simulating the energy performance of a typical Singapore office building. We used the DOE-2.1B program to simulate energy use.[4,5] We augmented hourly weather data for 1979 obtained from the National Climatic Center with measurements of Singapore's direct and diffuse solar radiation.[6] Figure 1 is a schematic of the floor plan of the reference building used. The full building has ten stories with a total conditioned area of 5250 m^2. We assumed the 100 m^2 of unconditioned interior zone on each floor to be thermally isolated from the remainder of the building.

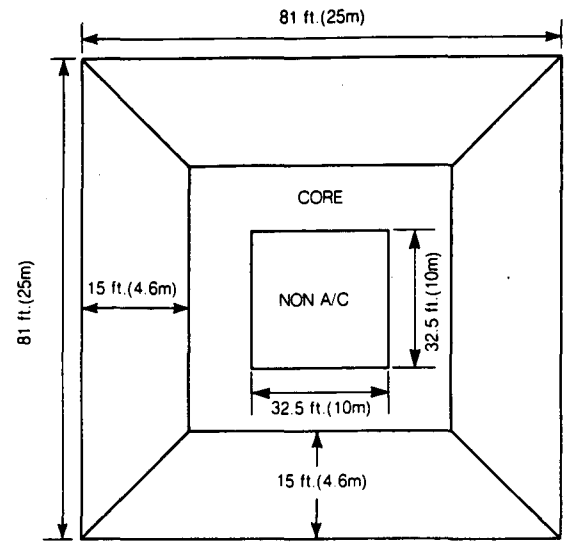

Figure 1. Schematic of typical floor of Singapore reference building: ten floors, 5,500 ft^2 of conditioned space/floor. (XBL 8512-5193)

This building represents a favorable design for daylighting because it has a large perimeter zone that can benefit from daylighting and a small core zone that cannot. However, the techniques developed in the present research can be accurately applied to various building designs.

To perform a large series of parametric studies easily, we used a single-floor module prepared by other researchers at Lawrence Berkeley Laboratory for an extensive study of daylighting in various U.S. locations.[7] Figure 2 shows two views of this module. The module can be viewed as a typical floor of a multi-story building. We applied results from the analysis of the module to the full building shown in Fig. 1.

The analysis of daylighting systems involved simulating photosensors at 5 and 10 m from the windows to measure interior lighting levels, control systems that adjust the artificial lighting levels within the perimeter zone of the building in response to light from outside the building, and internal shades or curtains to reduce glare. We did not consider more sophisticated or complex systems that might

*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.

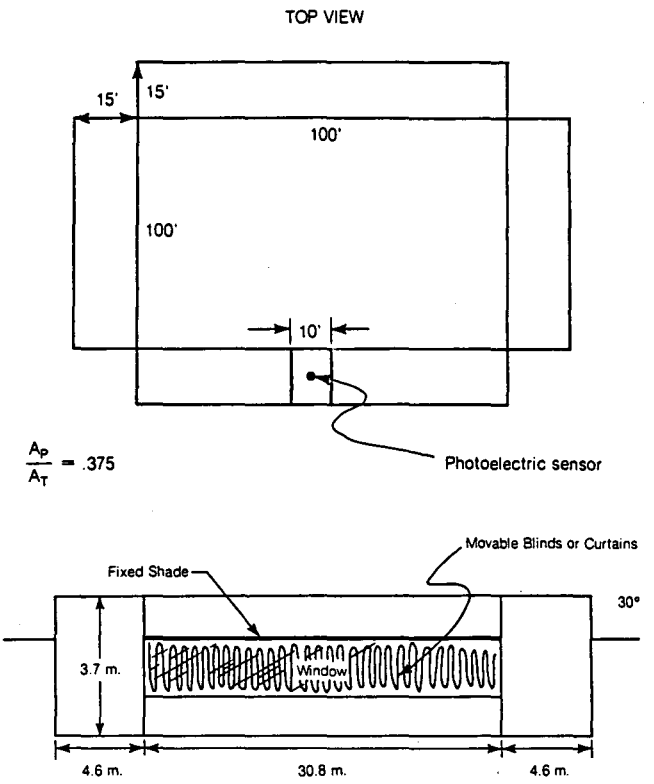

Figure 2. Module run to provide data for full DOE-2 analysis of reference office building. [(top) XBL 8512-5194, (bottom) XBL 8512-5195]

further increase energy savings or improve the quality of lighting, for example, "light shelves," automatic shading devices. Such additions are not likely to change the effectiveness of daylighting systems significantly in most applications.

Major Issues in the Analysis of Daylighting

The effects of daylighting depend on the characteristics of the external environment and of the building itself. For our purposes, the external environment is defined by the hourly weather data. Several characteristics of Singapore's sunshine are particularly relevant to daylighting possibilities. Although lying near the equator, Singapore does not receive intense solar radiation. High cloud density throughout the year limits the shine hours to 30 to 50 percent of daylight hours. Further, the high moisture content of the air creates a condition in which the diffuse component of solar radiation falling on a horizontal surface accounts for about 43 percent of the total radiation on an average day. Approximately 70 percent of the radiation on the vertical walls is diffuse. The high proportion of diffuse radiation in Singapore improves the performance of daylighting systems, as diffuse radiation provides usable light with relatively little glare.

A number of variables that are subject to the control of the building designer affect the performance of and energy savings resulting from daylighting systems. These include:

1. the window area (expressed for our purposes as window-to-wall ratio, WWR),
2. the amount of visible radiation transmitted through glass (TVIS),*
3. the area of the building that is in the perimeter zone (i.e., near windows),
4. the external shading of windows,
5. the lighting power (in W/m^2),
6. lighting level (in lx) in the perimeter zone of the building,
7. the type of controls used to reduce artificial lighting in the perimeter zone (specifically continuous or step controls), and
8. the methods of controlling glare problems introduced by daylighting (internal curtains, blinds, or shades).

Table 1 shows qualitatively how these eight parameters could be expected to affect lighting, cooling, and total energy use in a building. As the table shows, the direction of the net effect on total energy use is unclear for the key daylighting parameters. In this study we attempted to access all these relationships quantitatively. We then found ways to optimize use of daylighting techniques in a reference building by computer simulation. Later, we generalized these results in such a way that they could be applied to other Singapore office buildings.

The product of the window area of a building and the visible transmittance through the window material is a measure of the amount of visible radiation that is available to replace artificial light in the building. Window area divided by total envelope area is termed the window to wall ratio of a building (WWR). Thus, in a daylighted building the amount of lighting energy saved increases as the product of

*The passage of radiation through materials is impeded differently at different areas of the spectrum. The shading coefficient (SC) measures the fraction of total radiation that passes through a material, whereas the TVIS refers only to the visible part of the spectrum.

Table 1. Importance of eight factors on building energy use in a daylighted building.

Parameter[a]	Cooling	Lighting	Total
1. WWR	+	−	?
2. TVIS	+	−	?
3. Perimeter area	0	−	−
4. External shade	−	+	?
5. Light power	+	+	+
6. Light level	+	+	+
7. Continuous controls	−	−	−
8. Glare control	−	+	?

[a]An increase in each parameter causes an increase (+), decrease (−), or no change (0), in cooling, lighting, and total energy use in the building.

WWR and TVIS increases, and, in general, the savings rise asymptotically towards a maximum. However, because of the greater solar gain, increasing WWR × TVIS has the opposite effect on the cooling energy requirements of a building; thus, the overall effect on the total energy requirement of the building is indeterminate.

Figure 3 shows the effect of WWR × TVIS on the lighting energy requirements in the perimeter zone at three lighting levels: low, medium, and high. The building has continuous dimming controls, a lighting power of 16.2 W/m^2, and no external shading or window setback. As expected, the lighting energy use decreases as the product of WWR × TVIS increases, but the savings reach their potential maximum at moderate levels of WWR × TVIS. It is worth noting that a 45–65 percent reduction in lighting energy is achieved at the low value of WWR × TVIS of 0.12, the higher percentage savings being attained at lower lighting levels. A value of WWR × TVIS equal to 0.12 could, for example, correspond to a building with dark gray tinted single pane windows (shading coefficient = 0.44) that occupy 40 percent of the wall space. The upper bound of savings is just over 70 percent, and the difference between the various lighting levels becomes less significant as this value is approached. Figure 3 makes clear that large savings can be made easily by raising either WWR or TVIS, but that diminishing returns rapidly set in after WWR × TVIS reaches 0.12 to 0.15.

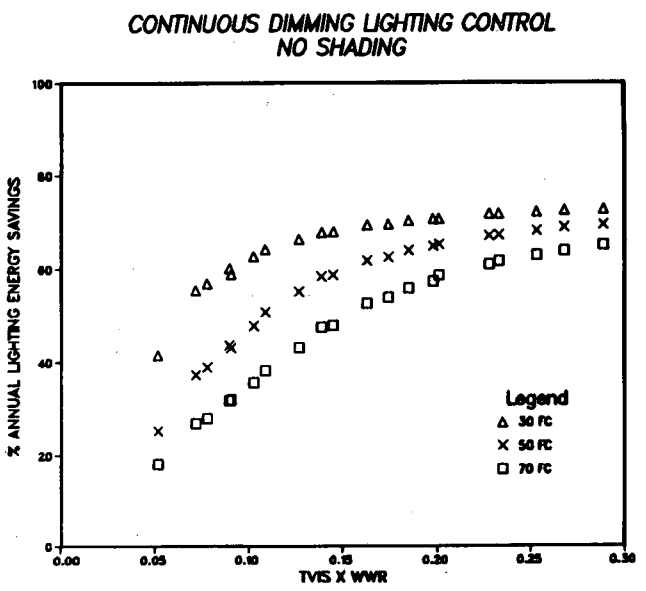

Figure 3. Effect of WWR × TVIS on lighting energy requirements in the perimeter zone. (XBL 8512-5196)

Figure 4 shows the effects of WWR and TVIS on the total energy use of the building. This simulation is based on a building with no external shading or window setback, continuous dimming controls, a medium illumination level, and a lighting power of 16 W/m^2. Also relevant to the interpretation of the results in Figure 4 is the fact that the perimeter area in the reference building constitutes 72 percent of the conditioned space. As we note later, the lighting savings as a fraction of total building energy use is directly proportional to the fraction of the conditioned and lighted space in the perimeter zone. Figure 4 illustrates the total reduction in energy use that can be expected to result from daylighting. We note that the lighting energy is continuously reduced as WWR × TVIS increases. However, the cooling and fan energy requirements increase with an increase in WWR × TVIS. Furthermore, cooling and fan energy requirements grow virtually linearly, whereas lighting energy savings flatten out. Thus, the energy requirements for this building reach a minimum at a WWR × TVIS of about 0.11, compared to the initial value of WWR × TVIS of about 0.14 in the reference building. This is close to the optimal configuration for daylighting in the reference building, yielding reductions in total energy use of 18.5 percent.

In summary, in the building studied, total energy use is minimized by adopting a WWR × TVIS of 0.11. However, at any given value of WWR × TVIS the percentage energy savings resulting from daylighting is close to 20 percent.

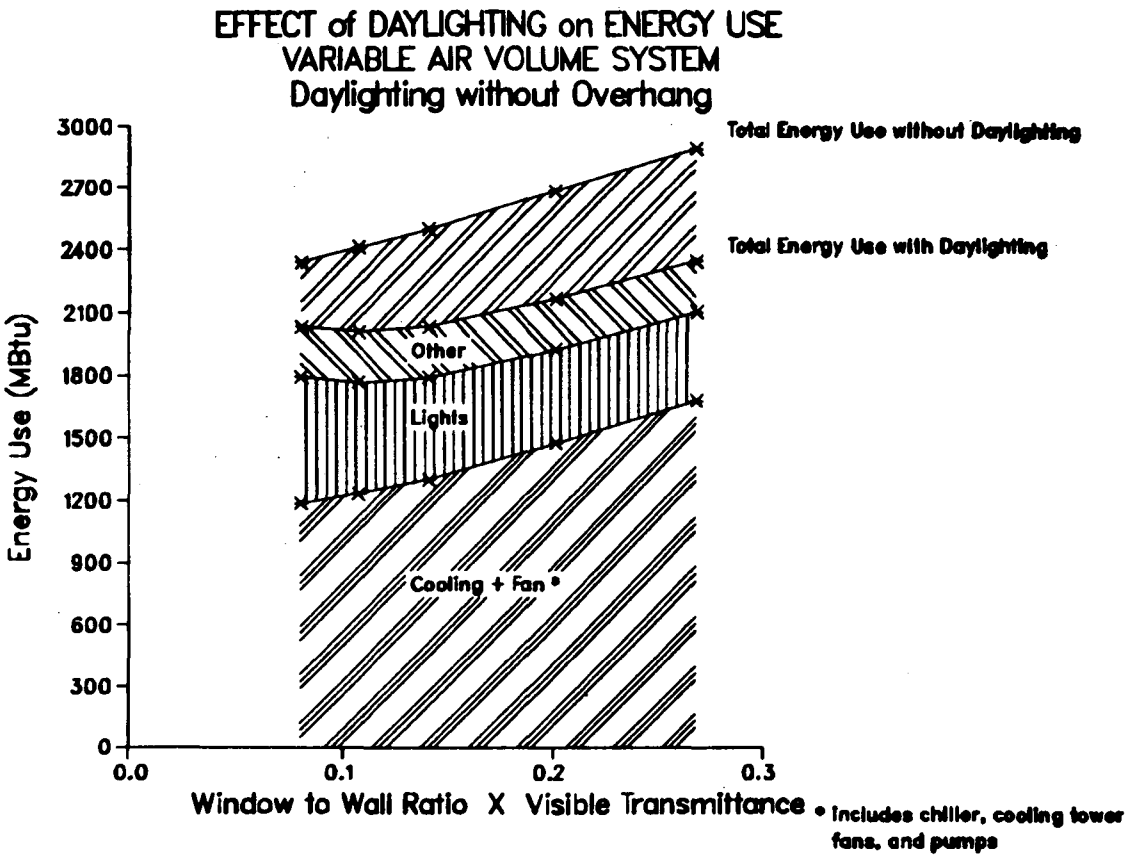

Figure 4. Effect of WWR × TVIS in total building energy use. (XBL 8512-5197)

CONCLUSIONS

The central assertion of this work is that it is possible to estimate the effects of the major design parameters on the performance of daylighting in commercial buildings in Singapore with a high degree of accuracy. The approach to building a model that obtains these estimates has been the use of results of DOE-2.1B simulations combined with a physical understanding of the factors affecting cooling and lighting energy requirements of buildings. The climate of Singapore simplifies the problem considerably, because of the relative constancy of solar gain and other climatic parameters throughout the workday and year.

We believe that the approach outlined in this paper has the potential for yielding accurate assessments of the impacts of daylighting in Singapore and other regions with hot climates. We further believe that this approach, when written for a microcomputer with proper graphical output and optimization routines, will provide architects and building engineers with a valuable tool for evaluating daylighting.

Finally, although the issue has not been directly addressed in this paper it is important to note that the potential savings from daylighting also include the possible benefits of reducing the peak load on the entire electricity system.[8]

PLANNED ACTIVITIES FOR FY 1986

Continuing research on daylighting in Singapore will extend the current work by developing a microcomputer code for assessing daylighting impacts and will analyze impacts of daylighting on the peak power requirements of the Singapore electrical system. In later years, we will extend the daylighting research to other members of ASEAN.

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Estimation of Energy Intensity by End Use for Commercial Buildings Using Conditional Demand Analysis*

I. Turiel, P. Craig, M. Levine, J. McMahon, G. McCollister,† and B. Hesterberg†

Despite a widespread application in the residential sector, the statistical technique known as conditional demand analysis has seen scant application in the commercial sector, due in large part to the greater diversity of commercial customers. This report describes the results of a study to estimate the energy intensities of major end-uses in commercial buildings in the service area of the Pacific Gas and Electric Company (PG&E).[1] We applied the conditional demand analysis technique to PG&E's 1982 Energy Use Survey data base to produce estimates of electricity and natural gas consumption per square foot for seven end uses consisting of space heating, air conditioning, lighting, water heating, cooking, refrigeration, and miscellaneous use. We provided these estimates for offices, food stores, restaurants, retail buildings, hotels and motels, hospitals, schools, warehouses, and miscellaneous buildings. The results of this study will be used for forecasting electricity use in the commercial sector.

*This work was supported by the Pacific Gas and Electric Company, through the U.S. Department of Energy under Contract No. DE-AC03-76SF00098.

†QED Research, Inc.

ACCOMPLISHMENTS DURING FY 1985

Methodology and Data

We used conditional demand analysis to model a customer's billed energy consumption as a function of building and business characteristics, climatic factors, and the stock of energy-using equipment. The technique requires high-quality data to obtain statistically significant estimates of average energy use per equipment type. Unfortunately, high-quality data are difficult to obtain for the commercial sector, and, as a result, this technique has seen very little application in the commercial sector. The lack of high-quality data is due to several factors. First, the diversity of customers is much greater in the commercial sector. Office buildings, for example, vary greatly in size. In some offices, windows open; in others, they do not. Some commercial buildings are occupied by diverse businesses; for example, a restaurant, a bank, and offices may occupy a large building.

Second, commercial buildings often have several electric or natural gas accounts. Conditional demand analysis depends heavily on complete billing data that are matched precisely with local weather data and with the characteristics of the building and occupants using the energy. It is difficult to design a data collection strategy that will properly match billing data with building and customer characteristics for a high percentage of possible circumstances.

Third, it is more difficult to measure the characteristics of energy-using equipment in the commer-

cial sector. For example, asking a household how many refrigerators it owns is more informative than asking the same question of a commercial customer, because, in that sector, energy use by refrigeration equipment is more variable from customer to customer.

To overcome these problems, several unique methodologies were designed for data collection and analysis. First, PG&E initiated an effort to design a data collection framework under which a customer's billing data could be matched to data obtained from a survey. This strategy matches multiple gas and electric accounts for each building by using name and address information. This forms a population of buildings from which a sample can be drawn and surveyed. In 1982, PG&E mailed questionnaires to such a sample and followed up by phone for customers who did not respond. Over 5,000 useful responses were returned to PG&E.

Second, this information was processed under PG&E's direction to remove inconsistent responses. The special characteristics of the commercial customers were considered in conducting this review. Third, we conducted the conditional demand analysis separately for buildings of different types. For example, the diversity among food stores is much less than that among all commercial buildings. Fourth, two techniques were designed for specifying the conditional demand equations for heating and air conditioning. In one, we used previous research experience and a knowledge of building physics, and, in the other, the weather sensitivity of each building was modeled separately. We tested both techniques in the conditional demand analysis and reported the results for the one yielding the best statistical fit (see Tables 1 and 2 below). These approaches were required because energy requirements for these end-uses depend on a complicated array of building and operating characteristics.

Annual Estimates of EUI's

The statistical results of this study include annual estimates of energy consumption per square foot for major end-uses in nine business types. We formed the business types by grouping buildings with similar business activities and energy-using equipment. We report the estimates for electric end-uses in Table 1 and for natural gas end-uses in Table 2. These estimates represent energy consumption per square foot of floor space (EUI's) that is served by that end-use. Floor space in buildings or parts of buildings that is not served by that end-use is not included in the computations used to derive the estimates.

These estimates do not indicate the amount of energy consumed by these end-uses or the relative percentages of energy consumed by each end-use. To derive these types of estimates, the energy consumption rates in this report must be multiplied by the number of square feet served by each end-use

Table 1. Energy utilization intensities—electricity (kWh/ft^2/year).

Building Type	Air Conditioning	Space Heating	Water Heating	Lighting	Refrigeration	Cooking	Ventilation	Miscellaneous
Offices	4.3	1.7	1.7	8.6	2.0	1.3	n.e.	0.2
Restaurants	7.4	4.1	6.6	6.8	16.0	17.9	n.e.	2.2
Retail	3.6	0.8	0.4	5.1	2.2	0.4	n.e.	3.7
Food Stores	2.0	1.4	0.9	14.2	24.1	1.2	n.e.	1.5
Warehouses	5.9	2.6	1.7	2.1	6.6	0.6	n.e.	0.1
Schools	2.1	0.5	0.4	2.0	1.4	0.6	0.6	2.0
Hospitals	4.7	1.3	3.2	7.4	1.9	1.5	3.0	0.9
Hotels/Motels	3.2	1.3	0.6	3.3	4.6	2.9	n.e.	2.6
Miscellaneous	6.2	2.9	n.e.[a]	3.9	4.0	1.8	0.5	2.0

[a]n.e. = not estimated.

Table 2. Energy utilization intensities—natural gas (kBtu/ft^2/year).

Building Type	Space Heating	Water Heating	Cooking	Clothes Dryers	Pools	Air Conditioning	Miscellaneous
Offices	26	9	n.e.[a]	n.e.	n.e.	n.e.	1
Restaurants	21	14	259	77	109	n.e.	n.e.
Retail	12	25	n.e.	148	n.e.	n.e.	3
Food Stores	34	2	49	n.e.	n.e.	n.e.	n.e.
Warehouses	37	11	33	33	n.e.	n.e.	2
Schools	35	5	1	n.e.	8	n.e.	1
Hospitals	75	75	41	n.e.	28	21	n.e.
Hotels/Motels	20	46	47	19	7	n.e.	n.e.
Miscellaneous	28	14	11	14	88	n.e.	2

[a]n.e. = not estimated.

and by the saturation of each end-use. Separate estimates of ventilation were possible for only three building types. For other building types, ventilation is contained primarily in the air conditioning or miscellaneous category.

The results in Table 1 indicate that combined air conditioning and ventilation intensity is highest in hospitals, restaurants, and buildings in the miscellaneous category, but lowest in food stores. Figure 1 plots the results for air conditioning. Schools are often closed during the summer, and refrigeration equipment in food stores draws heat from the building, reducing space cooling requirements. The electric space and water heating estimates are generally low relative to gas space and water heating, since electricity will most likely be chosen when these end-uses are not expected to be used very intensely. The highest estimates of electric space and water heating were found in restaurants. The lighting category includes both indoor and outdoor types of lighting. Lighting intensity is especially high in food stores, hospitals, restaurants, and retail stores. In food stores, lighting in refrigeration and freezer units is probably responsible for higher electricity consumption, whereas in hospitals, continuous operating hours is probably the reason. The refrigeration category includes both freezers and refrigerators. The energy intensity of refrigeration is high in food stores because of the high density of display units, many without doors. Refrigeration is also high in restaurants, where units are opened frequently and are often located in hot kitchens. Naturally, cooking use is very intense in restaurants. Ventilation was difficult to distinguish from the refrigeration end-use.

The results indicate that space heating use reaches extremes for two building types. It is very low in retail buildings and very high in hospitals. Long operating hours and strict temperature control are responsible for high space heating use in hospitals. Water heating use is also very high in hospitals, due to the need for extreme cleanliness and the domestic needs of the patients. Use of hot water is also high in hotels and motels. Water heating use is low in offices. Some use can be attributed to cafeterias, to hand washing in restrooms, and use by

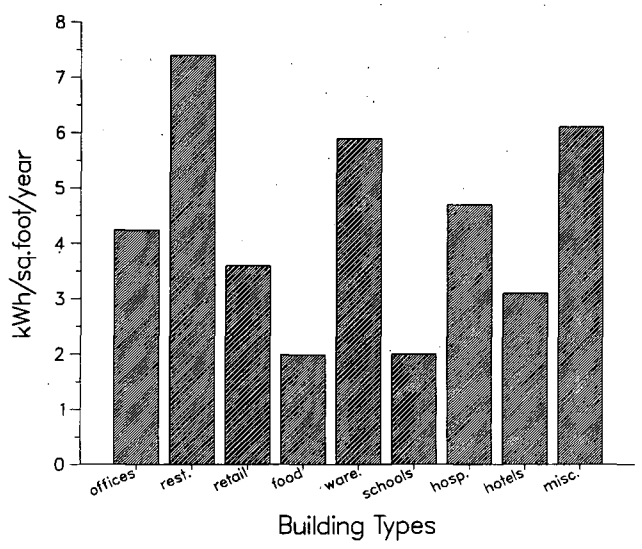

Figure 1. Energy utilization intensities—air conditioning. (XBL 8512-5199)

other business types in office buildings, such as restaurants. Also, schools and food stores use only small amounts of hot water. Cooking use is, of course, very high in restaurants and the food store category, which includes bakeries. It is also high in hotels and motels, which often house restaurants, and in hospitals, where three meals are cooked for patients each day. Use for clothes dryers is high in the retail and restaurant categories because these business types have laundries, and in hotels and motels for washing linen. Natural gas use for air conditioning was significant in only one building type, hospitals.

PLANNED ACTIVITIES FOR FY 1986

We plan to extend our FY 1985 research in several directions. These include a calculation of energy consumption by end use incorporating equipment saturations, and the stratification of EUI's by building age, climate zone, and building size. We also plan to gather data to improve our confidence in two of the EUI's: electric space heating and electric cooking. Finally, we will compare two methods of specifying seasonal energy consumption for space heating and air conditioning. These are the engineering approach and the statistical approach, which involve regressing monthly energy use on heating and cooling degree days.

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ECONOMIC STUDIES

The LBL Residential Energy Demand Forecasting Model*

J.E. McMahon and P. Chan

Computer models for projecting residential energy consumption at the end-use level have been in existence since the 1970's. The ORNL Engineering-Economic Model of Residential Energy Use[1] combines engineering information (costs and efficiencies of products available for purchase) and economic formulations (elasticities of demand separated into fuel choice, efficiency choice, and usage decisions) to provide simulations of future energy consumption at the end-use level. This approach attempts to consider the problem at a sufficient level of disaggregation to utilize engineering information as well as the important economic determinants of market behavior. The LBL Residential Energy Model[2] (see Fig. 1), has been developed as the next generation of computer model to provide

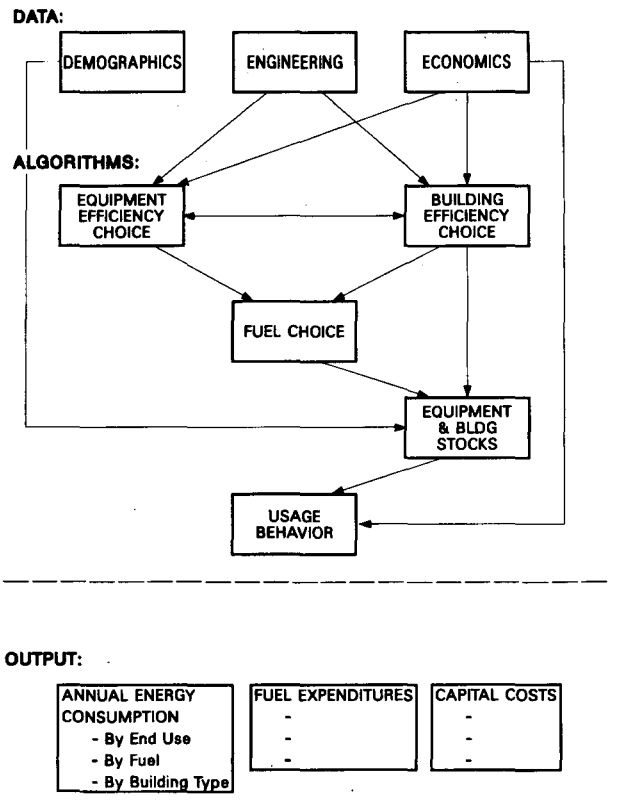

Figure 1. Logic diagram showing major components of LBL Residential Energy Model. (XCG 8412-13510)

*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.

improved policy analysis at the end-use level. The major improvements to our prior models include:

- representation of recent equipment efficiency trends;
- new techniques for forecasting future appliance efficiencies and annual appliance replacements; and
- extension of the model to include heat-pump space-conditioning systems.

The resulting forecasts agree more closely with recently reported energy consumption and provide lower estimates of future energy consumption.

ACCOMPLISHMENTS DURING FY 1985

During the past year we have made improvements in both the data and the model specifications.

Data

We have updated the data used by the model in several ways:

1. Housing starts/stocks. The 1980 Census gives higher estimates of the housing stocks than previous surveys, and shows an increase in the fraction of dwelling units in multifamily dwellings, at the expense of single family houses. At the same time, the construction forecast has been revised downward.
2. Energy cost projections. The last decade has seen dramatic changes in expectations regarding energy costs. For that reason, the assumed energy price projections have been altered repeatedly to keep abreast of changes in the market.
3. Income projections. The expected increases in real income were previously based on per capita estimates. The older estimates were optimistic, and have not been borne out by recent experience. In addition, we have changed the definition of the input variable to income per household. Currently, we assume 1.2 percent/year real growth in income per household after 1985.
4. Engineering Analysis. We developed a new aggregation procedure for combining data for various classes of products, e.g., manual defrost and frost-free refrigerators. We designed this method to extract as much information as possible, yet simplify the representation to a single curve for each product type.
5. Recent efficiency trends. We have included in the model the significant changes in design that have been reported by trade associations. Projections of future efficiencies are based upon the observed efficiencies and an analysis of the decision processes in the market since 1972.
6. Projected floor area per house. The older projections, extrapolating from historic trends, predicted in the year 2000 floor area per new house 20 percent above 1977 average house size. In view of the recent cessation of the trend toward larger houses, we have assumed that floor area per new house (within each house type) remains constant. Of course, the average floor area across the entire housing stock will continue to change, reflecting changes in the composition of the stock, e.g., the percent of all households that are single family.

Model Specification Changes

We made several key changes in the method of projecting future energy consumption in recent years:

1. Efficiency of new appliances. The improvements to the model are:
   1) Recognize the initial difference between the efficiency of a new appliance and the one it replaces.
   2) Include data on recent efficiency trends (through 1981 for many products) and begin projection after the last year of available data on efficiency of new units.
   3) Replace the algorithm for forecasting future appliance efficiencies. The new approach is based on a detailed analysis of market behavior over the last 10 years. We have replaced the market behavior algorithm. The original formulation was theoretical, since data on appliance efficiencies were not available. Recent work at LBL[3] using data made available during the Department of Energy analysis of proposed Consumer Product Efficiency Standards[4] (CPES) indicates that the original formulation, assuming an inverse relationship between energy price and unit energy consumption, forecasts higher efficiency improvements than observed in the market in the past 10 years. Appliance efficiencies have improved, but not by as much as had been forecast. What

appears to be relatively constant is the discount rate implicit in the market's appliance efficiency choice. On the whole, the tradeoff between operating cost and purchase cost by purchasers of appliances has not changed over time. Increases in energy costs have been reflected in the operating costs of appliances, and efficiencies (and presumably purchase costs) have increased. But, in most cases, the efficiency increases have only kept pace with rising energy costs, and do not yet indicate any change in the market decision-making process toward placing more emphasis on energy conservation. The details of the analysis of market behavior regarding efficiency choice are reported elsewhere.[3]

2. Construction practices in new houses. Just as new appliances are more efficient than those already in use, new houses are constructed in such a way as to reduce their space conditioning energy requirements relative to old houses. While measured data on the energy consumption of new houses are more difficult to obtain, the characteristics of new houses are known from national surveys. We used a physical model of heat transfer in a house (DOE-2.1 Building Energy Analysis Program[5]) to determine the annual energy consumptions for heating and for cooling, based on the characteristics of the house. Just as in the treatment of appliance efficiency, the new distinction made for thermal integrity is that the average new house has different characteristics and, therefore, different energy consumption from the average house already in existence.

3. Appliance retirements. The original formulation used an exponential retirement function, equivalent to retiring each year a constant percentage of the existing appliances of each age. We found data on retirement functions that give the percent of appliances that retire during each year after original purchase. The use of a vintaging approach achieves two purposes: 1) it eliminates the erroneous early retirement of young appliances (retirements in early years of the projection are therefore lower in the new method); 2) it captures the wave-like rise and fall of replacement sales, reflecting the aging of units purchased during peak economic and housing construction periods.

4. Energy use of retiring appliances. The old method accounted for the energy use of retiring appliances by retiring the energy use of the average unit in stock at the time. This was inaccurate, since units of several ages retire in any given year and the older retirees are likely to consume more energy (be less efficient) than newer models. In the new model, the retirees retain the unit energy consumption appropriate for their vintage. This change decreases the estimated energy consumption in future years. Since the greater portion of retiring appliances are older than the average appliance in stock, the new method assigns lower efficiencies to the retirees. As a consequence, the average efficiency of surviving appliances is higher than before.

5. Appliance price deflators. Another new feature is the ability to adjust the real purchase price of equipment each year of the forecast. Changes in the real price per unit may occur as technologies for the manufacture of a product evolve, or as economies of scale are realized. Different changes in the real price over time may be applied to different products and fuel types.

6. Explicit treatment of heat pumps. The old model subsumed heat pumps under electric central space heating and central air conditioning. The market shares of heat pumps were determined indirectly, using an old formulation to forecast the saturation of electric central space heating systems. The model has been revised to consider heat pumps as an explicit technology option for heating and cooling, and the new market share elasticities are under development.

7. Distribution of efficiencies. Early analyses of appliance efficiency standards assumed the 1978 distribution (number of shipments in each range of efficiencies) to be static for all time. We calculated the average efficiency in the presence of CPES exogenously by applying the CPES level to the 1978 distribution. Thus, the average efficiency in the presence of standards was assumed to be constant in all future years, unless exceeded by the average efficiency in the base case.

   The LBL model moves the 1978 distribution of efficiencies each year in the standards case so that the average efficiency agrees with the base case projection. The distribution is expressed in efficiencies as a fraction of the average, so that broadening of the distribution also occurs. To obtain the average efficiency in the standards case, all shipments with efficiencies less than the standard are assumed to be upgraded to the standard. Those with efficiencies at or above the standard are unaffected. We calcu-

late the shipment-weighted average from the adjusted distribution.

The new method has the advantages that: 1) the distribution of efficiencies changes in a way consistent with the change in the average efficiency; 2) the effect of the standard level diminishes with time, as the base case efficiencies move to or beyond the standards. Whereas in the old model the efficiency level in the standards case was a function of the standard level and of the 1978 distribution of efficiencies, the efficiency level in the new method is a function of the standard level and a distribution that changes (toward more efficient products) over time; 3) standards can be applied to individual classes of appliances. The change, while permitting analysis of standards affecting only some classes of appliances, does not alter the assumption of constant market shares of each class within an appliance type. For example, the fraction of new refrigerators that are top-mount, automatic-defrost remains constant over time. The framework could encompass a forecast of market shares by class, but we are aware of no such credible forecasts at this time.

8. Purchase cost/energy use formulation. The old model used a 3-parameter fit to the data from the Engineering Analysis[6] to obtain the continuous function of purchase cost to unit energy consumption. In work at LBL during the summer and fall of 1982, it became clear that the old formulation could lead to ambiguous results. Similar curve fits could be obtained, having different values for two of the three parameters. Since these parameters were important for calculating life cycle costs and aggregate implicit discount rates, the ambiguity was a problem.

   The solution in the new method is to use a 2-parameter formulation, which provides unambiguous values for the two parameters and provides good fits to the data points. Consequently, the shape of the purchase cost/energy use curves changed slightly for some products.

9. Twelve end uses. The old model considered only nine end uses, including the regulated products. The new model considers total residential energy consumption, composed of 12 end uses: central space heating, room space heating, room air conditioners, central air conditioners, heat pumps, water heaters, refrigerators, freezers, ranges and ovens, dryers, lighting, and miscellaneous. (The new end uses are heat pumps, lighting, and miscellaneous.) Lighting and miscellaneous had been considered in even older versions of the old model, but to the exclusion of dryers and room space heaters, since the total number of end uses had been fixed. Separating heat pumps from central air conditioners eliminates the overcounting of savings for a policy applied only to non-heat-pump air conditioners, and permits consideration of different standard levels for heat pumps and conventional central air conditioners.

   Another important change involves reformatting the inputs, such that one set of inputs is defined for use with all end uses (such as housing starts), while additional sets of input are defined specific to each end use. The new model has been generalized so that it is now easy to analyze subsets or the full set of end uses, as desired.

10. Graphical output. We added the capability of obtaining graphical output for most of the key outputs. The pictorial presentation, as opposed to tabular, facilitates analysis of large amounts of data, and is particularly useful when analyzing trends over time or the difference between two scenarios. Among the graphs that can be produced are: total residential energy consumption over time, fuel prices over time, efficiency trends over time, and residential purchases of appliances by type over time. Some graphs illustrate the difference between two sets of results, usually a base case and a policy case: energy savings over time, net present benefit by end use (bar graph), efficiency of new units over time, and percent energy savings by end use by house type over time.

PLANNED ACTIVITIES FOR FY 1986

We will incorporate the results of a new analysis of market share elasticities (see D. Wood, *et al., Market Share Elasticites of Home Heating and Cooling Systems* in this volume). By replacing the current algorithm, we will greatly improve the forecast of the penetration of heat pumps into the space heating/cooling market. In addition, we will capture the influence of choosing central air conditioning on the selection of a heating system. Also, we will introduce competition between room and central heating systems as a function of the operating and equipment costs of the alternatives.

We will increase the level of detail in two areas: efficiency forecasts and regional differences. First, rather than forecasting the average efficiency for a product, the forecast will consider each class. For

example, frost-free top-mount refrigerators will be treated as distinct from manual-defrost refrigerators. This will permit a direct comparison of the forecast with actual designs of appliances, making better use of the detailed engineering information in the data base.

Second, we will expand the data base for the USA to treat separate regions. The model will then recognize the differences in climate and energy prices in different parts of the country. In the process, we will update the data base using the 1980 Census and other recent sources.

Finally, we will separate the effects of efficiency changes and equipment capacity (e.g., the size of refrigerators or air conditioners) on energy consumption per unit.

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Economic Impacts of Residential Conservation Programs on Electric Utilities*

E. Kahn, C. Pignone, J. Eto, J. McMahon, and M.D. Levine

Conservation programs mandated by the federal government will have economic impacts on electric utilities that may or may not be favorable to those utilities. The impact depends upon local circumstances such as the rate structure, the utility's marginal costs, and the nature of local utility regulation. To understand how these factors interact, it is necessary to model the hourly demand changes associated with particular conservation programs. Methods of economic valuation must then be developed to reflect the gains and losses associated with load shape changes.

This article describes two case studies of residential conservation programs involving utilities with substantially different marginal costs. These cases, Detroit Edison and Pacific Gas and Electric, illustrate the economic method used to estimate economic impacts. The impacts of conservation programs are unfavorable in the former case, but quite favorable in the latter.

ACCOMPLISHMENTS DURING FY 1985

Most economic analyses of conservation programs focus on the consumer perspective. It is equally important, however, to characterize the impact of conservation programs on utility earnings. To estimate these effects, we modified an accounting measure known as earnings before interest and taxes (EBIT) to include the changes in utility investment associated with particular conservation programs.

EBIT is simply the difference between revenues and costs. The economic value of marginal load changes is the difference between marginal revenues and marginal costs. Investment costs must be considered along with operating costs. Depending upon circumstances, the relevant investment costs may be for peaking turbines or baseload facilities.

The marginal revenues associated with conservation programs are specific to particular rate

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schedules. Where a utility has more than one residential tariff, the conservation impact must be estimated for each rate classification. Our analysis is conducted using the LBL Residential Energy Model[1] applied at the rate class level. This means forecasting electricity sales for each tariff class with and without the conservation program. Since the LBL model is quite data-intensive, the base-case forecast (made with limited data) commonly involves some adjustment to achieve correspondence with utility estimates.

Once the quantity change associated with conservation programs has been estimated, it must be applied to the sales frequency distribution in a way that will account for the nonlinearity of the revenue response. It is necessary to know the distribution of sales over the rate tiers because tariff schedules typically have price distinctions based on the quantity consumed.[2] Marginal revenue is determined by changes in the entire sales distribution induced by conservation programs. We adopted the block-adjustment method to model these changes. Figure 1 illustrates the procedure.

Figure 1 shows two distributions, o and n. Suppose n represents the sales distribution after conservation, o the distribution before conservation, and $B_{1,o}$ = 340 kWh/month, the consumption level above which the electricity price changes from p_1 to p_2. If we know only the distribution o, its mean value μ_o, and the mean value μ_n of n, we estimate the fraction of sales below $B_{1,o}$ for the distribution n as follows. We know that n will have a larger fraction of sales below $B_{1,o}$ than o. Instead of estimating the change for the curve o to the curve n, we increase the quantity of electricity for which p_1 will be the price. This is done by defining a new price boundary, $B_{1,n}$, which is greater than $B_{1,o}$ by the ratio μ_o/μ_n. The fraction of sales at p_1 is then read off curve o at the point $B_{1,n}$. In Fig. 1, this point is labeled a.

The error of this procedure is measured by comparing point a with point b, both projected to the vertical axis. Point b is just the intersection of $B_{1,o}$ with the curve n. In this case, the block adjustment method predicts too small a fraction of sales at price p_1. The revenue impact of this error depends upon whether $p_2 > p_1$. If it is, then the block adjustment method overestimates revenue. For the purposes of case study analysis, the block adjustment method must be used until a superior alternative is developed.

Marginal costs present a different problem. Here, it is necessary to aggregate all effects up to the system level, taking due account of the diversity of load profiles across individual users. We use the LBL Hourly Demand Model[3] to perform this aggregation. Figure 2 illustrates the kind of result that comes from testing particular conservation programs. This figure shows hourly residential loads for a projected peak day in 1996. The largest load impact shown here results from a mandated efficiency standard for central air conditioners that would require a seasonal energy efficiency ratio (SEER) of 12 by 1987.

Once load impacts have been aggregated from rate classes and spread over the hours of the year, they are then valued at the utility's marginal cost.

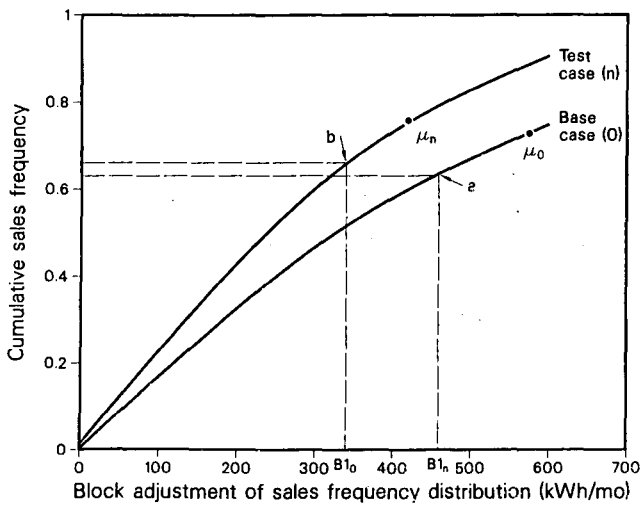

Figure 1. Cumulative sales frequency of electricity vs. block adjustment of sales frequency distribution. (XCG 844-13045)

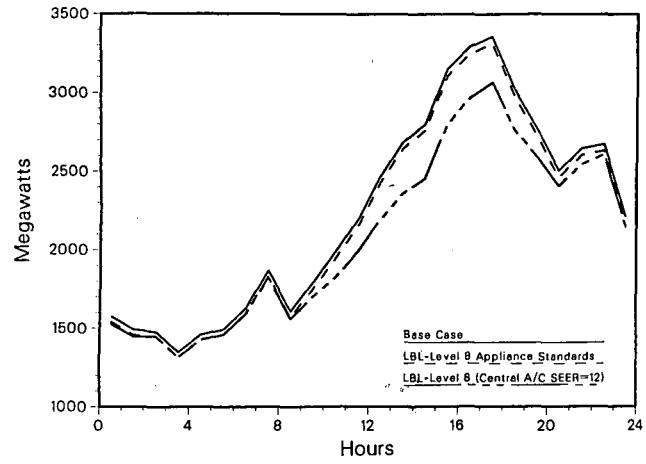

Figure 2. Projected Pacific Gas and Electric Company residential hourly load profiles for a peak summer day in 1996 (base case and two conservation scenarios). (XCG 848-13191)

Marginal cost has two components, capacity and energy. Capacity costs are typically concentrated in those hours of the year where the utility system loss-of-load probability is greatest. Simulations of Pacific Gas and Electric Company (PG&E), for example, show that the highest 10% of the load hours in July and August typically account for over 95% of the annual system reliability risk. Therefore, only these hours have capacity value.

Marginal energy costs are also estimated by system simulation methods. Typically, these methods involve load aggregation techniques that suppress the chronological sequence of loads.[4] The simulated result is summarized in the form of a load duration curve resembling Fig. 3. The monotonically declining curve represents the number of hours in the simulated period for which the system load is at a given level. Because the loads are sorted by magnitude, chronological features are lost. The supply system is dispatched to serve loads in economic order. Figure 3 shows the order in which Detroit Edison plants would serve projected 1988 loads. The plants with lowest operating costs serve the base load. These are placed at the bottom of the load duration curve (LDC). Plants that intersect the LDC are marginal producers.

Figure 3 shows how the average marginal cost over a given period can be calculated as a weighted average of the marginal costs of the plants intersecting the LDC. The appropriate weights are the marginal fractions, which are shown at the top of Fig. 3. They represent the fraction of hours for which a given plant is the marginal producer. This is the vertical projection of the points at which that plant intersects the LDC.

Applying marginal energy-cost results to a particular conservation program requires an estimate of how to translate load impacts from the hourly demand model to the more aggregated level of the LDCs. For case study purposes, we make relatively simple assumptions that result in proxies that are easy to use.

Case study results are described in detail elsewhere.[5,6] The results for Detroit Edison (DECO) are uniformly negative. Because of substantial excess capacity, DECO has low marginal costs. Therefore, the benefits of conservation in terms of the value of avoided energy production are small. There is no benefit in avoided capacity costs. The case of PG&E is more complex. This utility has high capacity costs. While its marginal energy cost is higher than DECO's, it is still less than marginal revenue. The net result of these effects depends upon the particular conservation program.

Figure 4 shows results for a conservation program corresponding to one of the two for which the effects are illustrated in Fig. 2. The positive net gain of this program is due principally to the capacity value associated with high-efficiency central air conditioners. Other programs without this component show much smaller benefits.

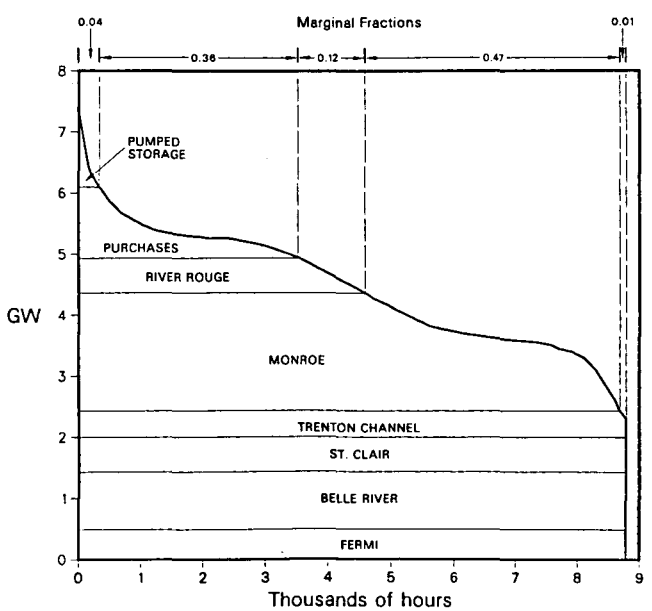

Figure 3. Fully dispatched load duration curve for Detroit Edison Company, 1988 projection. (XCG 844-13046)

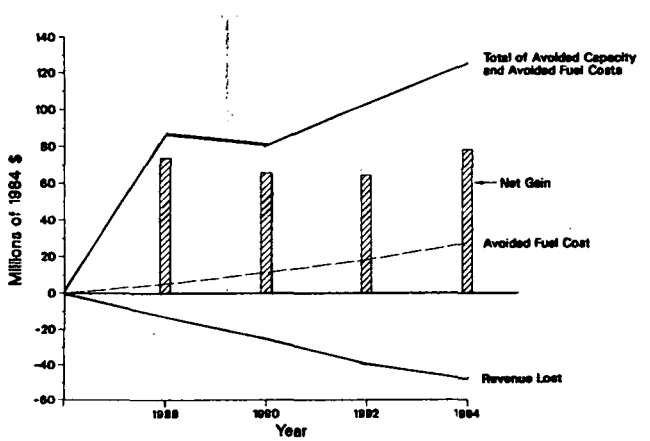

Figure 4. Economic impacts of central air conditioner standards (SEER = 12) on PG&E. (XBL 851-985)

PLANNED ACTIVITIES FOR FY 1986

We will complete case studies of the financial impacts of appliance efficiency standards on the Nevada Power Company and the Texas Power & Light Service Territory of the Texas Utilities Electric Company. The Nevada Power Company study will feature independent simulations of avoided production costs.

We will also perform detailed analyses of the techniques and models available for direct integration of load shape changes into traditional supply planning models.

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Regional Analysis of the Economic and Institutional Environment for New and Enhanced Utility Programs*

W. Yen-Wood, E. Kahn, and M. Levine

The advent of increasing marginal costs and slower growth in the 1970's along with a proactive regulatory environment has spurred utilities to explore alternatives to traditional planning methods. "Least-Cost Planning" and "Demand-Side Management" strategies, emphasizing the need to optimize the cost and timing of electricity supply and demand, are emerging as credible alternatives to conventional supply planning focusing on construction of large-scale central station power plants. In this context, the objective of the Utility Overview Study is to provide conservation policy makers with an estimate of *where* and *when* investor-owned utilities (IOUs) will be interested in promoting energy conservation as an alternative to importing power or constructing new power plants for meeting future energy demand. The project began in FY 1984 with the identification of Energy Supply/Demand Balance and Cost, Ratemaking, and Political/Institutional Environment as three key factors relevant to utility decision-making concerning energy conservation programs. The initial Overview Study database included 85 IOUs representing 70% of total generation in the U.S. Due to the complexity of the utility planning environment (geographical boundaries of electric utilities may be defined by their service areas, investment in generation capacity, or power exchange agreements) as well as data availability considerations, we have incorporated several levels of analysis in the Overview Study. Table 1 presents the selected Utility Overview Study indicators by North American Electric Reliability Council (NERC) Region, DOE Electric Region, State, Utility, and annual data. We present the findings of the Overview Study at the level of DOE Electric Regions because these subregions approximate the flow of energy transfers among power pools within the NERC Regions.

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Table 1

UTILITY OVERVIEW STUDY INDICATORS

Factor/Indicator	NERC Region	Annual Data	Electric Subregion	Annual Data	State	Annual Data	Utility	Annual Data
I. Energy Supply/Demand Balance Factor								
POG	•	1984			•	1983		
PLCC	•	1982,83	•	1983	•	1982	•	1982
GROWTH	•	1983-92,1984-93	•	1984-93				
YEARS	•	1982,83	•	1983	•	1982	•	1982
PAC	•	1982			•	1982	•	1982
SUR/DEF, SHORT	•	1984-93	•	1984-93				
RYN, SubRYN,	•	1984-93	•	1984-93				
II. Ratemaking Factor								
RATES	•	1982			•	1982		
RES							•	1983
COM							•	1983
IND							•	1983
FARM							•	1983
CWIP	•	1982,84			•	1982,84	•	1982-84
III. Institutional Factor								
INSUL	•	1981			•	1981	•	1981
AUDIT	•	1981			•	1981	•	1981
SOLAR	•	1981			•	1981	•	1981
COGEN	•	1981			•	1981	•	1981
LOAD	•	1981			•	1981	•	1981
OTHER	•	1981			•	1981	•	1981
INVEST	•	1985			•	1985		
ASSESS	•	1985			•	1985		
INCENT	•	1985			•	1985		
OPTION	•	1985			•	1985		
STAT	•	1985			•	1985		

LEGEND

POG - Percent Oil/Gas
PLCC - Percent Low-Cost Capacity
GROWTH - Average Annual Growth Rate
YEARS - Years Until Expensive Energy is Needed
SUR/DEF - Regional Capacity Surplus/Deficit
SHORT - Subregional Capacity Surplus/Deficit
RYN - Regional Years to Need for New Capacity
SubRYN - Subregional Years to Need for New Capacity
RATES - Inverted Rate Structure
RES - Inverted Rate Structure - Residential Sector
COM - Inverted Rate Structure - Commercial Sector
IND - Inverted Rate Structure - Industrial Sector
FARM - Inverted Rate Structure - Farm Sector
CWIP - Construction Work in Progress

INSUL - Incentive for Insulation
AUDIT - Incentive for Energy Audit
SOLAR - Incentive for Solar Application
COGEN - Incentive for Cogeneration
LOAD - Incentive for Load Management
OTHER - Other Conservation Incentives Potential
INVEST - Utilities Required to Invest in all Cost-Effective Energy Conservation Prior to New Energy Resources
ASSESS - State Conducted Assessment of Conservation Resource Plans
INCENT - Commission Offers Conservation/Load Management Incentives
OPTION - Demand-Options Included in Required Utility Resource Plans
STAT - State has Statutory Authority to Require Utility Investment in Conservation and Load Management

XBL 863-777

ACCOMPLISHMENTS DURING FY 1985

Preliminary selection of indicators for the Utility Overview Study was carried in FY 1984 at the NERC Region, State, and Utility level. In FY 1985, we proceeded with the development of the Need for New Capacity indicator at the regional and subregional level, an update of the Regional Potential Low-Cost Capacity indicator, and extension of this analysis to the level of Electric Regions. We also adopted a new set of rate structure and institutional indicators based on newly available data. The results for indicators are compiled in a final report.[1]

Background Note on the NERC Regions and DOE Electric Regions (Subregions)

The NERC was formed by the electric utility industry in 1968 after the Northeast blackout to promote the reliability and adequacy of power supply in the United States and Canada. NERC has nine regional councils comprising nearly all the electric utilities in North America. Both NERC and DOE have defined subregions to support smaller area analyses of power supplies. NERC Subregions and DOE Electric Regions were designated in accordance with historic associations among neighboring utilities, contractual and informal power pools, and practical system operating considerations. Figure 1 shows the location of NERC Regions and DOE Electric Regions. Some States may belong to more than one NERC Region or Electric Region. Three interconnected transmission networks provide for the distribution of electricity in the U.S.: The Eastern Interconnected System (EIS), the Western Interconnected System (WIS), and the Texas Interconnected System. Cooperation among utilities within interconnected systems may take place through sale of bulk power, power pools, wheeling, and joint projects.

Regional Indicators of Potential for New and Enhanced Energy Conservation Programs

The economic impact of energy conservation on electric utilities consists of changes in projected revenue resulting from lost sales and avoided costs. In the short run, if conservation reduces peak demand, it will increase the profitability of total electricity sales by lowering average production costs. In the long run, conservation may involve load shape changes that shift the balance between peak and base load generation. Average production costs will decline if peak generation declines more than base load.

We consider marginal energy cost of baseload generation to be the most influential factor determining the near-term potential for conservation among investor-owned utilities operating in an environment of increasing marginal costs. Need for new generating capacity will reinforce the potential for conservation in regions where there is no low-cost energy, and promote consideration of strategic conservation programs where there are temporary surpluses. Active interest in conservation by public service commissions together with a favorable ratemaking environment will encourage the early adoption of conservation programs.

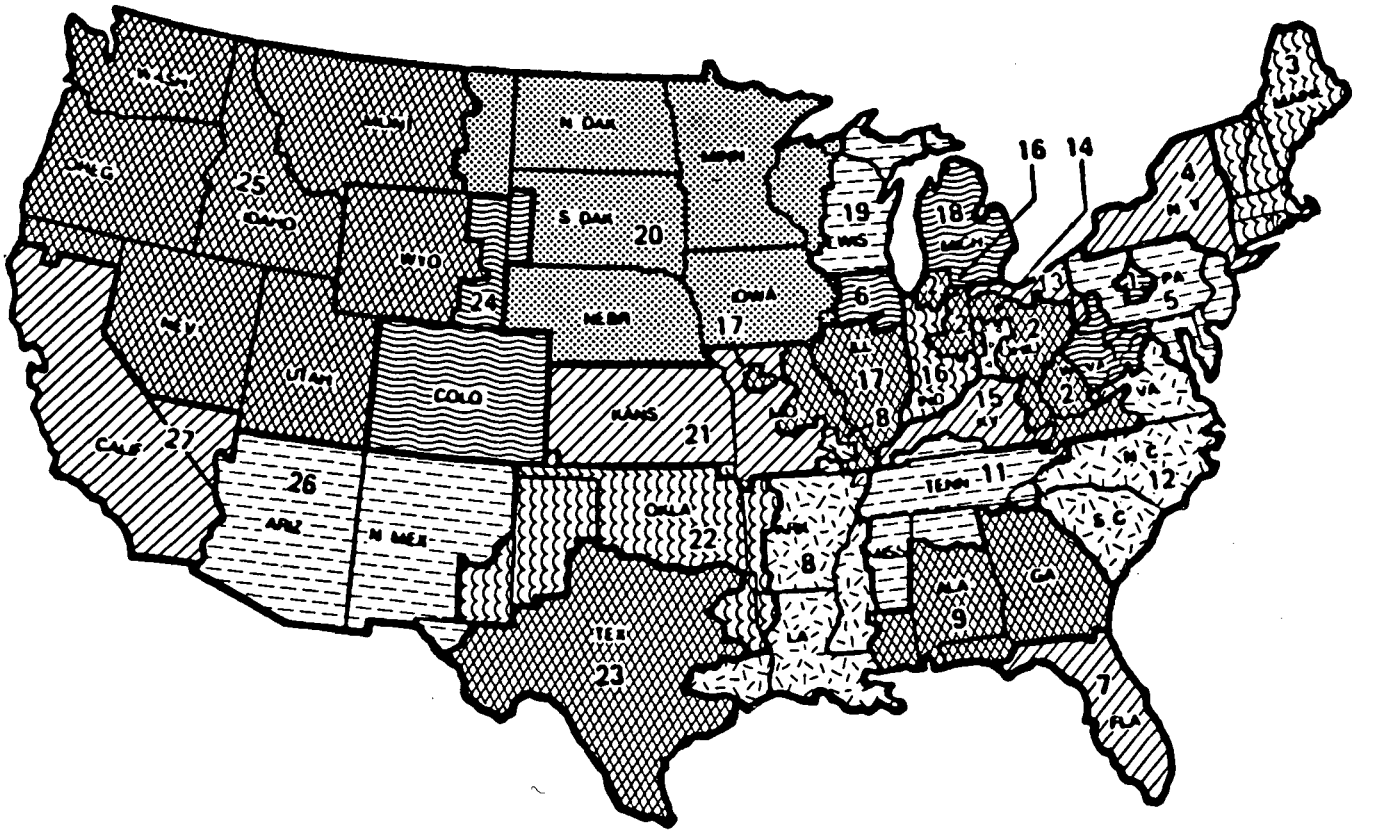
Of the indicators defined to analyze the energy supply/demand balance, the ratemaking context, and the political/and institutional environment, we consider the six that best characterize the conditions under which utilities will be favorable to energy conservation are: (1) High Oil Backout Potential, (2) Little or No Marginal Low-Cost Base Power, (3) Relatively High Growth, (4) Early Need for New Capacity, (5) High Risk for New Power Plants (Low CWIP), and (6) Favorable Institutional Environment.

Figure 2(a) thru 2(f) highlights the results for these indicators by State and Electric Regions.

High Oil Backout Potential

Following the 1973 Oil Crisis, utilities have embarked upon programs to use less expensive coal and nuclear fuels in order to decrease dependence on more expensive oil and natural gas. Possible shortages of critical fuels and increasing marginal costs may prompt utilities in Regions heavily dependent on oil and gas to consider conservation as an important aspect of their demand-side strategy.

Figure 2(a) shows percent of oil/gas generation to total thermal generation among the states in 1984.[3] It should be noted that in 1984, actual oil and gas capability accounts for a greater proportion of generating capacity than that reflected by data on generation because of the gradual shift in fuel sources. At the regional level, oil and gas fired generation is expected to account for the largest share (40%–60%) of total generation in the (NPCC—Rhode Island, Massachusetts, Connecticut, New York) and Southwest (ERCOT—Texas, SPP—Louisiana, Oklahoma); between 10–20% in the West (WSCC—primarily California) and the Mid-Atlantic States (MACC—New Jersey); and about 7% in the Southeast (SERC—primarily Florida). This pattern of fuel consumption among regions is expected to



RELIABILITY COUNCIL/Electric Region

ECAR

1. APS (Allegheny Power System)
2. WOIM (West Virginia-Ohio-Indiana-Michigan System)
13. WPANCO (Western Pennsylvania-North Central Ohio Group)
14. CDH (Cincinnati-Dayton-Hamilton Group)
15. KY (Kentucky Group)
16. IND (Indiana Group)
18. LMS (Lower Michigan Systems)

ERCOT

23. No Subregions

MAAC

5. No Subregions

MAIN

6. CECO (Commonwealth Edison Company)
17. SCIM (South Central Illinois-East Missouri Group)
19. WIUM (Wisconsin-Upper Michigan Systems Group)

MAPP

20. No Subregion

NPCC

3. NEPOOL (New England Power Pool)
4. NYPP (New York Power Pool)

SERC

7. FCG (Florida Electric Power Coordinating Group)
9. SOCO (Southern Company Group)
11. TVA (Tennessee Valley Authority)
12. VACAR (Virginia-Carolinas Group)

SPP

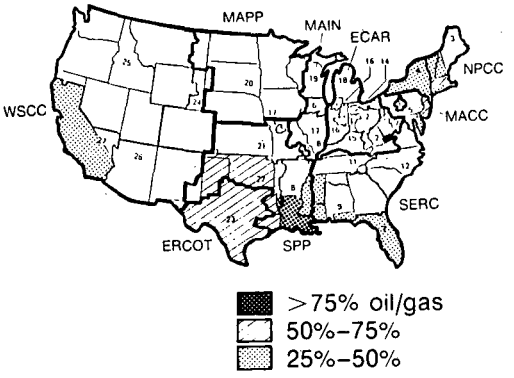
8. MSGS (Middle South-Gulf States Group)
21. MOKN (Missouri-Kansas Group)
22. OKLA (Oklahoma Group)

WSCC

24. RMPA (Rocky Mountain Power Area)
25. NWPP (Northwest Power Pool Area)
26. AZNM (Arizona-New Mexico Power Area)
27. CASN (California-Southern Nevada Power Area)

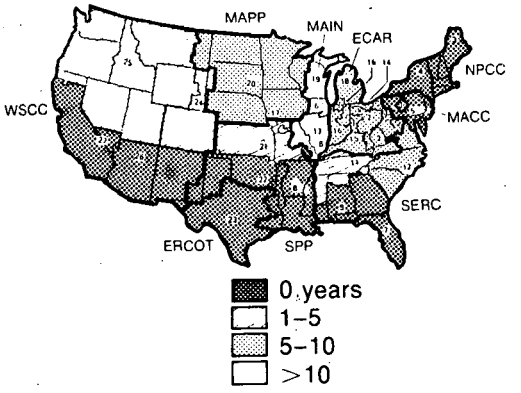
Figure 1. NERC regions and DOE Electric regions. (XBL 8510-11733)

a) High Oil/Gas Backout (POG)



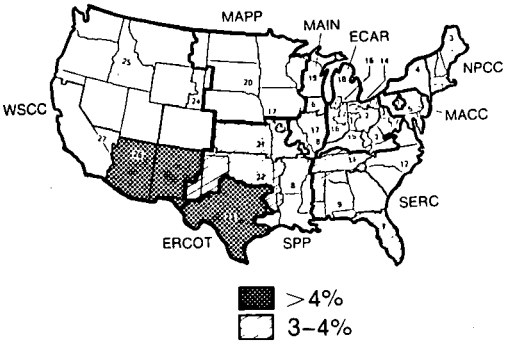
Source: 1984 State data

b) Little or No Marginal Low-Cost Power (Projected 1986 Estimate for YEARS)



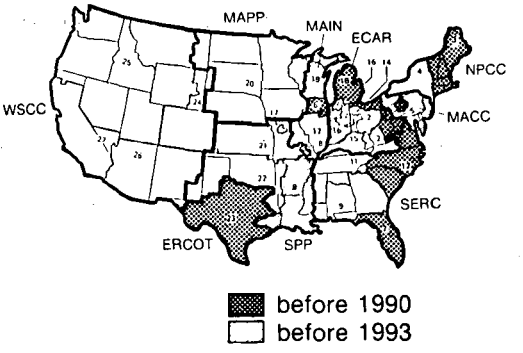
Source: DOE, 1984 Subregional data

c) Relatively High Growth 1984-1993 (GROWTH)



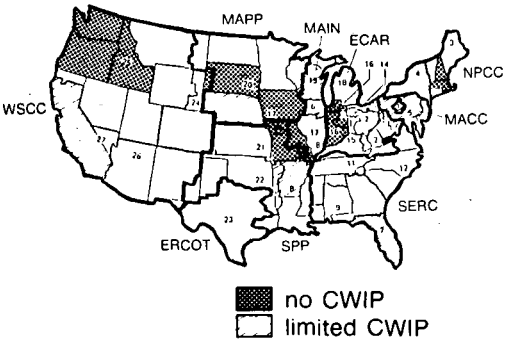
Source: NERC, 1984 Subregional data

d) Early Need for New Capacity – Case II (SubRYN-2)



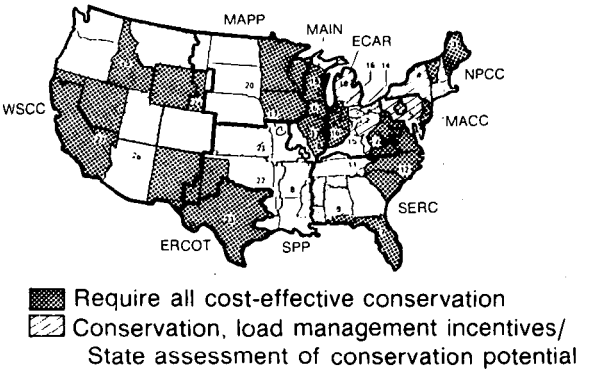
Source: DOE, 1984 Subregional data

e) High Risk for New Power Plants (Low or No CWIP)



Source: NARUC, 1984 State data

f) Institutions Favor Conservation



Source: Schneider Survey, 1985 State data

Figure 2. Selected indicators of potential for new and enhanced electric utility conservation programs. (XBL 862-9106)

remain about the same during 1984–1993 because of the projected slowdown in capacity additions.[4]

Little or No Marginal Low-Cost Base Power

We define Potential Low-Cost Capacity (PLCC) as the potential to produce energy from all inexpensive generating facilities (hydro, nuclear, coal and imports*) in excess of that needed to meet the utility's total demand. Utilities with excess low-cost marginal power have a near-term incentive to increase revenues because the primary cost associated with selling an addition kWh is fuel cost, which is usually lower than the average cost of electricity. They are unlikely to favor energy conservation because increase sales represent an opportunity to generate additional profits. In an environment of increasing marginal cost, utilities with little or no available cheap power will tend to favor conservation.

Where PLCC > 0, we estimate the number of years (YEARS) until the available low-cost energy is used up given the average (1984–1993) growth rate projected for the region and subregion. We believe that utilities will consider conservation as an option for meeting electricity demand so long as the supply of low-cost marginal energy is less than ten years, the time needed for construction and licensing of new coal and nuclear power plants.

Figure 2(b) is a map of the 1986 YEARS estimate at the Electric Region (subregional) level. Based on 1983 data, the subregions projected to have no low-cost power in 1986 are located in:

ERCOT (Electric Region 23, Texas),
MAAC (Electric Region 5, Pennsylvania, New Jersey, Maryland),
NPCC (the New England States),

and portions of:

WSCC (Electric Region 25—Northwest Power Pool, Electric Region 26—the Arizona–New Mexico Group,
Electric Region 27–California–Southern Nevada Group),
SPP (Electric Region 8, Middle South Utilities/Gulf States Utilities Group, and Electric Region 22, Oklahoma Group)
SERC (primarily Electric Region 7, Florida Coordinating Group, and Electric Region 9, the Southern Company Group).

The subregions projected to have 1 to 5 years of low-cost power available are located in:

SERC—Electric Region 11, The Tennessee Valley Authority Group,
SPP—Electric Region 21, Missouri–Kansas Group,
WSCC (Electric Region 24, Rocky Mountain Power Pool).

Given the growth rates in these regions, surplus cheap power is expected to be fully utilized by 1990.

Electric Regions located in ECAR and MAPP are projected to have between 5 and 10 years of surplus low-cost energy. Their interest in conservation may depend on the availability of other least-cost options for meeting projected demand.

The economic environment for conservation is unfavorable in the three Electric Regions located in MAIN. Electric Region 6—the Commonwealth Edison Co., Electric Region 17—the Illinois– Missouri Group, and Electric Region 19—the Wisconsin–Upper Michigan Systems Group are all projected to have greater than 10 Years of surplus cheap power in 1986. However, surplus low-cost power in the MAIN Reliability Council area is projected to decrease from 12 years to less than 10 years by 1990.

Relatively High Growth

The rate of growth of electricity demand plays a significant role in utility decision-making, as it influences electricity production, the type and quantity of fuel consumed, capacity expansion, reliability, financing, and end-use electricity prices. Lower than expected demand growth exerts upward pressures on electricity prices as new plants come on line. Higher than expected rates of electricity demand increase the need for capacity required to ensure reliable electricity supplies.

Figure 2(c) shows the subregions where projected 1984–93 average annual net energy growth rates are greater than 3%.[5] The subregions with relatively high electricity demand growth (>4%) are WSCC (Electric Region 26—Arizona–New Mexico) and ERCOT (Electric Region 23—Texas). SPP (Electric Region 21 and 22, Missouri–Kansas and Oklahoma Groups), and SERC (Electric Region 7 and 11, Florida Coordinating Group and Tennessee Valley Authority Group) have projected average electricity demand growth rates between 3% and 4%.

*We assume in general imports will be lower-than-average cost power. Formally, PLCC is expressed as:

$PLCC = |(C + N + H + NP) - T)|/ T$, where

C = Coal Capacity$_i$ (MW) · 8760 hr · 0.65 (capacity factor),

N = Nuclear generation (MWh)

H = Nuclear generation (MWh)

NP = Net purchases (MWh)

T = Total Net Generation.

Early Need for New Capacity

We focused on data for years where adjusted reserves at the subregional level are less than 5% as the most favorable case for conservation.* Regional and subregional surplus/deficit (SUR/DEF, SHORT) at time of summer and winter peak is computed as capability (MW) in excess of or needed to meet a 5% reserve margin.[6] Based on the demand growth rate in the region and subregion, we estimated the Years Until New Capacity is Needed (RYN, SubRYN) for when surpluses will be used up.

We examine two cases of projected capacity additions. Case I is our analyses of when and where new capacity is needed based on DOE regional data for planned capability 1983–1992.

Under Case I, need for new capacity in the later half of the 1980's is projected for:

ECAR (Electric Regions 1, 13, 14, 18),
MAIN (Electric Region 6),
NPCC (Electric Region 3), and
SERC (Electric Regions 11, 12);

and in the early 1990's for:

MAPP (Electric Region 20), and
ERCOT (Electric Region 23).

Figure 2(d) shows the timing of need for new capacity† among the Electric Regions under Case II. In Case II, planned capability is adjusted for nuclear power plants not in operation or likely to be canceled.‡ The near term consequences of such reductions in planned capacity may be less reliable electricity supplies, power purchases, higher utility oil and natural gas consumption, and/or higher electricity prices. Projected shortages deepen for all affected regions in Case I and are expected to occur earlier for ERCOT (1989) and MAAC (1990). Several of these NERC Regions may need to institute conservation programs or plan for new capacity or purchases (provided adequate transmission facilities are available) at some peak periods during the coming decade if the predicted conditions actually occur.

*DOE defines Adjusted Reserve as: Planned Capability − (Outages + Scheduled Maintenance + Other Unavailability) − Peak. An adjusted reserve margin of 5%–7% is consider sufficient to ensure reliability. This is roughly equivalent to capacity margins of 15%–20% used by the industry.

†We present the earlier of summer or winter estimates.

‡We considered the following nuclear power plants as likely to be canceled: Midland 2 (ECAR), South Texas 2 (ERCOT), TMI-1 (1985 only), TM1-2, Limerick 2 (MAAC), Seabrook 2 (NPCC), and Grand Gulf 2 (SPP).

High Risk for New Power Plants (Low CWIP)

Given the lengthening construction period for new power plants, utilities are increasingly advocating the partial or total inclusion of financing costs in the rate base *as they occur* to improve their cash flow during the construction period. Concurrent ratebasing of construction financing costs is generally referred to as CWIP—Construction Work in Progress. If the full cost of financing new power plant construction is allowed in the rate base, the long-term attractiveness of conservation compared with new construction as a way of balancing supply and demand will decline because this treatment of financing costs reduces the economic disincentive for building unnecessary capacity. Figure 2(e) shows the location of states that disallowed or limited CWIP in 1984[7]:

NPCC (New Hampshire, Massachusetts, Connecticut, and Rhode Island)
WSCC (Washington, Oregon, Idaho, California),
MAPP (S. Dakota, Nebraska, Iowa),
SPP (Missouri, Arkansas),
ECAR (Indiana),
MACC (Pennsylvania),
and SERC (Florida).

It is important to keep in mind that regulatory policy is this area is volatile; state public service commissions may expand or contract allowance of CWIP based on their evaluation of both the need for new capacity and a utility's financial condition.

Favorable Political/Institutional Environment

In FY 85, we updated the indicators for the Political/Institutional Factor with the results from a recent survey of public service commissions conducted by the Office of Congresswoman Claudine Schneider.[8,9] We consider the requirement of conservation investments as the most favorable indicator of regulatory interest in energy conservation, followed by the existence of state conservation, load management incentives, and/or assessments of conservation potential. Nineteen states require utilities to demonstrate that they are acquiring all cost-effective conservation and load management before investing in new energy sources. Eleven states have instituted either conservation or level management incentives, and 28 states have conducted independent assessments of conservation potential.

Figure 2(f) shows the states with the most favorable environment for conservation. They are located in:

ECAR (Indiana, Michigan, Ohio);
ERCOT (Texas),
MACC (New Jersey, Pennsylvania, Maryland);
MAIN (Wisconsin, Illinois, Michigan);
MAPP (Iowa, Minnesota);
NPCC (Maine, Vermont, Delaware, New Hampshire, Connecticut, Massachusetts, New York);
SERC (Virginia, North Carolina, South Carolina, Florida, Alabama, Mississippi);
SPP (Kansas, Texas); and
WSCC (California, Nevada, Idaho, Wyoming, Oregon, Montana, New Mexico).

Combining the Selected Indicators

Table 2 summarizes the result of the six indicators for the NERC regions. "No Low-Cost Power" and "Early Need for New Capacity" are weighted as key indicators of merit in the composite rating of "Favorable to Conservation."

There is a clear need now to consider conservation in Group A: Texas (ERCOT—Electric Region 23), the mid-Atlantic (MAAC—Electric Region 5), the Northeast (NPCC—Electric Region 3 and 4), Florida (SERC—Electric Region 7), the Mid-South (SPP—Electric Region 8), and the West (WSCC—Electric Regions 25, 26, and 27) are areas that have regions with no surplus low-cost capacity. Also, on economic grounds, the potential for conservation is good in Group B, regions with 1–5 years of cheap energy, which includes SERC—Electric Regions 9 and 11 (Southerm Compny and TVA), SPP—Electric Regions 21 (Missouri–Kansas) and 22 (Oklahoma), and WSCC—Electric Regions 24 (Rocky Mountain).

Group C represents regions that are borderline favorable to conservation. They include Electric Regions in ECAR (1, 13, 14, 16, 18), MAPP (20), and SERC (12) that have an estimated 5 to 10 years of surplus low-cost energy. Some Electric Regions in ECAR and SERC are expected to need additional new capacity by the early 1990s. Utilities in these areas may consider appropriate "least-cost" capacity-enhancing alternatives along with conservation research at this time.

Utilities within regions belonging to Group D are considered unlikely to implement conservation programs in the near term. The availability of CWIP in Electric Regions 2 and 15 (ECAR), combined with an expected 5 to 10 years surplus of low-cost energy, would also make conservation a less competitive option in the long term compared with construction of small power plants. There may be some tension between the institutional environment and economic reality for Electric Regions in MAIN. For 1986, Electric Regions 6, 17, 19 in MAIN are projected to have greater than 10 years of low-cost surplus energy. PUCs in these regions seem to favor conservation, whereas the economics of excess low-cost capacity would tend to push utilities to promote greater sales in the short term. Utility interest in conservation for MAIN may become more favorable after the 1990s when the region will have less than 10 years of surplus low-cost power and a need for new capacity to ensure reliability of power supply.

Limitations of the Study

The purpose of our regional analysis is to segment the market for energy conservation among investor-owned utilities having different system characteristics to support DOE policy and program planning efforts. Selected indicators focused on key economic measures of avoided costs, and provide a qualitative review of the ratemaking and institutional environment. At the next step of implementation, actual design and selection of conservation programs, will require careful examination of program costs/benefits at the utility level.

PLANNED ACTIVITIES FOR FY 1986

Although the work on this study was completed during the past fiscal year, related research is continuing. Two new LBL utility case studies—Texas Power and Light and Nevada Power—are in process to examine the effect of appliance standards on utility revenues. Two computer models developed to analyze generation expansion (EGEAS) and load management alternatives (LMSTM) are being evaluated to determine through hands-on experience the application of these models in comparing supply and demand-side options. A third project, jointly funded by PG&E and DOE, examines methodological issues associated with demand-side management programs for a large utility. When completed, these studies will provide useful information for the development of conservation programs and Least-Cost initiatives.

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Table 2

FAVORABLE TO CONSERVATION - 1986

NERC Reliability Region	DOE Electricity Region	Identification	High Oil Backout	No Low-Cost Power	High Demand Growth	Early Need for Cap	No/Low CWIP	Favorable Inst.	Composite Rating
ECAR	1	Allegheny Power Systems (APS)		~		+		+	C
	2	W. Va-Ohio-Ind-Mich Systems (WOIM)		~				+	D
	13	W. Pa-No. Central Ohio (WPANCO)		~		+		+	C
	14	Cincinnati-Dayton-Hamilton (CDH)		~	+		+	+	C
	15	Kentucky Group (KY)		~				+	D
	16	Indiana Group		~		+	+	+	C
	18	Lower Michigan Systems		~	+	+		+	C
ERCOT	23	Texas Interconnected Systems Group (TIS)	+	+	+	+		+	A
MACC	5	Pennsylvania-New Jersey-Maryland Interconnection (PJM)		+		+			A
MAIN	6	Commonwealth Edison Co. (CECO)				+		+	D
	17	Illinois-Missouri Group (ILLMO)						+	D
	19	Wisconsin-Upper Michigan Systems Group (WUMS)				+		+	D
MAPP	20	Mid-Continent Area Power Pool		~			+	+	C
NPCC	3	New England Power Pool (NEPOOL)	~	+		+	+	+	A
	4	New York Power Pool (NYPP)	~	+			+	+	A
SERC	7	Florida Coordinating Group (FCG)	~	+	+	+		+	A
	9	Southern Company Group (SOCO)		+					B
	11	Tennessee Valley Authority Group (TVA)		+	+	+			B
	12	Virginia-Carolina Group (VACAR)		~		+		+	C
SPP	8	Middle South Utilities/Gulf States Utilities Group (MSGS)	+	+		+	+	~	A
	21	Missouri-Kansas Group (MOKAN)		+	+		+	+	B
	22	Oklahoma Group (OKLA)	+	+	+			+	B
WSCC	24	Rocky Mountain Power Pool (RMPP)		+				~	B
	25	Northwest Power Pool (NWPP)		+				+	A
	26	Arizona-New Mexico Group (AZNM)		+	+			+	A
	27	California-So. Nevada (CASN)	+	+			+	+	A

Indicators: + - Very Favorable; + - Favorable; ~ - Borderline Favorable

Capacity Rating: A - Very Favorable; B - Favorable; C - Borderline Favorable; D - Unfavorable

Source: LBL Report LBL -21056

Note: To derive the composite rating, we assigned the following numerical weights and scales to selected indicators. Scales for each indicator are shown in parenthesis, in the order for "very favorable," "favorable," and "borderline favorable."

1. High Oil Backout = 1, (3, 2, 1)
2. No Low-Cost Power = 5, (5, 3, 1)
3. High Demand Growth = 1, (3, 2, 1)
4. Early Need for New Capacity = 1.5, (3, 2, 1)
5. No/Low CWIP = 1, (3, 2, 1)
6. Favorable Institutional Environment = 1, (3, 2, 1)

For the composite rating, Very Favorable is A = > 27; Favorable is B = 18 to 26; Borderline Favorable is C = 9 to 17. Unfavorable is D = 0 to 8.

XBL 862-443

3. Edison Electric Institute (1984), *Statistical Yearbook of the Electric Utility Industry/1983,* Washington, D.C. Table 22–Generation by Fuel, Total Electric Utility Industry (by State and Kind of Fuel), p. 31.
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Energy Efficiency Choice in the Purchase of Residential Appliances*

H. Ruderman, M.D. Levine, and J.E. McMahon

This study provides a quantitative analysis of the behavior of the market for the purchase of energy efficiency in residential appliances and heating and cooling equipment. Accurate forecasts of residential energy use require quantitative assessments of market decisions about energy efficiency. The results of our investigation of market behavior can lead to a better understanding of the barriers to investment in energy conservation. Understanding market behavior over time is a prerequisite to an evaluation of the need for and the importance of policies to promote energy efficiency.

The importance of such an analysis to DOE's assessment of its proposed Consumer Products Efficiency Standards relates to its use in forecasting the behavior of the market. Most of the direct impacts of standards (energy savings, net present benefit, and cost of proposed standards) depend critically on the degree to which higher efficiency would be incorporated into new products in the absence of standards. The research will lead to improvements in the methodology and data in the base-case residential energy forecast, thereby improving estimates of the impacts of the standards.

*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.

In this study, we examine the historical efficiency choices for eight consumer products: gas central space heaters, oil central space heaters, room air conditioners, central air conditioners, electric water heaters, gas water heaters, refrigerators, and freezers. These products were selected because (1) they account for a major part of residential energy consumption, (2) data on efficiency and costs are readily available, and (3) they are under consideration by DOE for efficiency standards.

We characterize the behavior of the market for these eight products by a single quantity, which we call an aggregate market discount rate. The aggregate market discount rate quantifies the behavior of the market as a whole with respect to energy efficiency decisions. Choices by individual purchasers are constrained by the decisions made by the manufacturers of appliances, the wholesalers or retailers who distribute them, and third-party appliance installers such as builders or plumbers. The value of the discount rate reflects the actions of all these decision makers. It is determined empirically from data on the efficiency and cost of appliances purchased between 1972 and 1980. By examining the historical behavior of the market discount rate, we can better understand the factors that influence efficiency choice. Furthermore, the market discount rate can be used as a parameter in forecasting future residential energy consumption. A paper on this work will appear in *The Energy Journal;* it is also available as an LBL report.[1]

ACCOMPLISHMENTS DURING FY 1985

Most of the work for this study was completed during FY 1983 and was described in the previous

annual report. During FY 1985, effort focused on four aspects of the study: (1) calculating payback periods as well as aggregate market discount rates; (2) recalculating discount rates based on monthly compounding rather than annual compounding; (3) examining aggregation bias in the estimation of payback periods; and (4) completing a paper for publication in a refereed journal. This article will discuss the first three aspects.

Payback Period Calculation

The simple payback period is defined as the time needed to recoup an initial investment in energy efficiency. Numerically, the payback period is equal to the increase in purchase cost divided by the decrease in annual operating cost. Assuming the operating costs change only because fuel use decreases, we have:

$$\text{Payback} = \frac{\Delta PC}{FP \cdot \Delta E} = \frac{-1}{FP}\frac{dPC}{dE} \quad , \qquad (1)$$

where PC is the purchase cost, FP is the fuel price, and E is the annual energy consumption. For a continuous cost-efficiency curve, the payback period is the present worth factor.

The purchase cost versus energy use relationship that we used was an exponential curve of the form:

$$E = E_\infty + (E_o - E_\infty)\exp[-A(C-1)] \quad . \qquad (2)$$

where:

- $C = PC/PC_o$,
- E = annual unit energy consumption (UEC),
- E_o = highest UEC,
- E_∞ = minimum UEC attainable at infinite purchase cost,
- PC = purchase cost corresponding to E,
- PC_o = purchase cost corresponding to E_o,

and A is a parameter determined from the shape of the curve. Using this expression, the simple payback period is:

$$\text{Payback} = \frac{PC_o}{A \cdot FP \cdot TI}\frac{1}{(E - E_\infty)} \quad , \qquad (3)$$

where we have included a factor TI to account for the possibility that the thermal integrity of the structure may change with time.*

*This factor is defined as the relative energy use at different levels of thermal integrity; hence, TI decreases with better insulation and lower air infiltration.

Presenting this study's results in terms of a payback period has some advantages. First, the concept is simpler than that of an aggregate market discount rate and may be closer to what consumers use to make decisions. Second, the payback period does not depend on assumptions about appliance lifetimes and compounding periods. This point will be discussed in more detail below. Finally, discount rates are nonlinear functions of the measured parameters; hence, their values can be very sensitive to small changes in the measurements.

Average payback periods during the years 1972–1980 for the eight appliances are presented in Table 1. Except for air conditioners, the market required an average payback of less than 3 years for an investment in improved appliance efficiency, and for electric water heaters and freezers, the requirement was less than 1 year. Most of the payback periods appear to be stable over time. This supports our previous conclusions that the market for energy efficiency is not working well and that it has not shown much improvement over the past 10 years despite rapid increases in energy prices and increased awareness of energy conservation.

Table 1. Payback period (in years) for appliances, 1972–1980.

Appliance	1972	1978	1980
Gas central space heater	2.98	2.38	2.21
Oil central space heater	2.33	1.70	1.18
Room air conditioner	5.11	4.77	5.25
Central air conditioner	4.96	4.16	5.18
Electric water heater	0.48	0.41	0.41
Gas water heater	1.50	1.07	0.98
Refrigerator	1.35	1.45	1.69
Freezer	0.60	0.67	0.72

Monthly Discounting

The most common method for evaluating discount rates is to take the time period as 1 year. However, this will underestimate the discount rate when the payback period is shorter than 1 year. Since fuel and electricity bills are paid monthly, we chose a one-month time period for evaluating the market discount rate. It is calculated by solving the following equation for the discount rate r, given a present worth factor or payback period:

$$PWF = \sum_{t=1}^{N}\frac{1}{(1+r)^t} = \frac{1}{r}\left[1 - \frac{1}{(1+r)^N}\right] \quad . \qquad (4)$$

The appliance lifetime N in this equation is expressed in months. An exact calculation would take into account the monthly variation in energy use by each appliance and the month in which it was bought. Since these data are not available, we average over 1 year so that the monthly energy use is one-twelfth of the annual. In presenting our results, we calculate an annualized discount rate $\bar{r}$ from the monthly discount rate r, using the relationship:

$$1 + \bar{r} = (1 + r)^{12} \quad .$$

The revised annualized discount rates shown in Table 2 are higher than those calculated previously for a period of 1 year. The difference is largest for appliances with short payback periods. Although the values are different, our original qualitative results—that market discount rates for most appliances are higher than those expected under perfect market conditions—still hold. These results support the viewpoint that market forces alone are not enough to eliminate the substantial economic inefficiencies in appliance energy use.

Aggregation Bias

In calculating the payback period and market discount rate, we assume that all consumers will have an average energy use corresponding to the sales-weighted efficiency factor (SWEF). If, in fact, there is a distribution of energy consumption due to differences in efficiency choice or usage, the average market payback period of these users may be different from that calculated from the average energy use. We investigate this aggregation bias in two cases: one in which there is a distribution in energy use and a second in which there is a distribution in appliance efficiency. In the first case, the average payback period is greater than that calculated from the average energy use (and the discount rate is less). In the second case, the direction of the aggregation bias depends on the ratio of average efficiency to the maximum efficiency corresponding to E_{∞}. The amount of bias depends on the width of the energy and efficiency distributions.

To estimate the magnitude of the aggregation bias, we used data on the distribution of efficiency of central air conditioners in 1980 published by the Air-Conditioning and Refrigeration Institute.[2] The average efficiency (SEER) was 7.76, with a standard deviation of about 10%. This gives an aggregation bias of about 1%. Biases of this size are small compared to the uncertainties caused by measurement error in the SWEF and other data used to calculate the payback period.

Table 2. Aggregate market discount rates (in percent) for appliances, 1972–1980.

Appliance	1972	1978	1980
Gas central space heater	39	51	56
Oil central space heater	52	78	127
Room air conditioner	20	22	19
Central air conditioner	19	25	18
Electric water heater	587	825	816
Gas water heater	91	146	166
Refrigerator	105	96	78
Freezer	379	307	270

PLANNED ACTIVITIES FOR FY 1986

Work during FY 1986 on consumer behavior will concentrate on collecting data on individual purchases of appliances. We will follow up on a TRENDEX survey of refrigerator purchases to get information on the model bought, from which information we can determine its capacity and efficiency. On the basis of these data, we will develop an econometric model of refrigerator purchases relating capacity and efficiency choice to household characteristics such as family size and income.

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An Investigation of the Reasons for the Rapid Market Penetration of Electric Heat Pumps in the Residential Sector*

Mark D. Levine

Imagine the task of an analyst in 1973 whose job it was to predict the sales of heat pumps in residential buildings in the United States. Such an analyst would be aware of the reputation of heat pumps for unreliability. If the analyst were old enough, he might remember the experience with heat pumps in Florida during the 1940's, in which the high failure rate and low reliability of the product virtually destroyed a potentially lucrative market. The analyst would note that the sales of heat pumps had remained relatively constant for many years, at about 2 percent of the total residential market. The analyst would perform economic calculations, and conclude from these calculations that heat pumps were not nearly competitive with gas heat systems and central air conditioners. He would check with manufacturers and discover that no major breakthroughs had occurred in heat pump systems.

The conclusion from this information would be inescapable: heat pumps would probably continue to serve its small market niche. However, there would be no reason to suppose they would increase their market share significantly in the near future (the next ten or fifteen years). A good analyst, working in a position of responsibility, could easily have staked his reputation on such a forecast. If he had done so, he would have been wrong. Starting in 1973, sales of heat pumps in the residential market began a slow ascent, increased again in 1974, and showed dramatic increases in 1975, 1976, and 1977. By 1977, the small market niche had grown to almost eight times the sales in 1972. Relatively constant sales through 1980 gave way to another large increase in 1981. By 1981, sales of heat pumps were more than ten times the 1972 levels; they commanded 20 percent of the total residential space heating market and 50 percent of the electric heating market.

*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.

ACCOMPLISHMENTS DURING FY 1985

The basic issue addressed by this study was: how can we account for the rapid and seemingly unexpected sales of heat pumps in the United States during the past decade? Are the factors that caused this dramatic increase in market acceptance likely to continue? What basis can be used to forecast future heat pump sales in the residential sector? From the experience of the past decade, what factors are most likely to influence the marketability of heat pumps?

Approach

The first step of the analysis consisted of a series of telephone interviews with individuals in various regions of the United States who were involved in and knowledgeable about the factors affecting heat pump sales. We chose nine locations for which heat pump sales were relatively high (greater than 30 percent of the residential heating market in 1979), with the idea of identifying the causes of high sales.† These nine "case studies" were: Phoenix, Arizona; Philadelphia, Pennsylvania; Tennessee Valley; state of Iowa; portions of the state of Kentucky; state of Maryland; southern and central Indiana; Cincinnati, Ohio; and northeast Ohio.

The second step—carried out at the same time as the case studies— involved the collection of all national (and, where possible, regional) data relevant to the forecasting of heat pump sales. This included: estimates of heat pump performance in different climates; cost of fuels and competing heating and cooling systems; national and regional sales data; and related information. These data provide the standard information base for forecasting. As we have noted, this is the information that—taken alone—served to mislead our hypothetical analyst forecasting heat pump sales in 1972. As we will observe, the current economic data without the information from the case studies fail to explain the phenomenal growth in heat pump sales in the United States.

The third step in the analysis involved the development of analytic techniques to forecast future heat pump sales in the United States. The approach is a mixed estimation technique involving both the use of a discrete choice and an enginnering-economic model. The forecasting uses data concerning both the traditional economic factors and the market factors identified in the case studies of heat pump sales.

†One location, Philadelphia, Pennsylvania, was in a state with lower than 30 percent saturation of heat pumps. It was included because the city represented an example of several factors likely to increase the market for heat pumps in the future.

We have presently completed a first effort on the first two steps. As noted, nine case studies have been carried out and the generally available economic data relevant to sales forecasts have been gathered.

Results

Interpretation of the Rapid Increase in Heat Pump Sales during the Mid-1970's

Sales of heat pumps had been steady from 1963 through 1971. Total U.S. sales were between 76,000 and 88,000 for all but one of these years—97,000 heat pumps were sold in the United States in 1969. Annual sales to the residential sector were virtually constant from 1966 through 1971 (ranging between 60,000 and 68,000), having increased from 49,000 in 1963. Residential sales increased to 80,000 in 1972, but this increase was due to high levels of residential construction in that year rather than to any basic change in the market for heat pumps.

Thus, it was reasonable to conclude that the heat pump industry had achieved a comfortable albeit small niche in the market and expected to see little change in its activities after 1972.

The shock of the oil embargo had some impact on heat pump sales. Total sales grew 20 percent in 1973, almost 20 percent in 1974, and another 20 percent in 1975. The primary effect of the oil embargo and OPEC price increases was on the price and availability of liquid fuels. Heat pumps were not competing strongly in those regions (especially the Northeast) in which fuel oil was a major fuel for space heating. Both gas and electricity prices were rising from 1973–1975, but electric heat pumps were not nearly competitive on a life-cycle cost basis as was gas heating at that time. Furthermore, the higher first cost of electric heat pumps *vis a vis* gas furnaces was a further disincentive to the purchase of heat pumps.

We thus interpret the increase in sales of electric heat pumps in the 1973–1975 period as largely due to effective marketing strategies that recognized the substantial concern about *future* availability and cost of fossil fuels that had permeated large segments of American society. A mature and stable industry had demonstrated the reliability of heat pumps throughout the 1960's. Thus, having a product with a proved track record, the industry was able to benefit from changing perceptions among potential customers.

Had no other developments in fuel availability and cost taken place after 1975, it is unclear whether heat pumps would have continued to increase sales, maintained its market position, or lost sales to competing space conditioning systems. The economics in 1975 was not favorable to heat pumps in competition with gas furnaces. However, the industry had built up into marketing activities and could probably maintain its roughly 5 percent penetration of the residential space heating market. Thus, a good guess is that, had events in the U.S. energy system not radically changed in 1975, annual sales of heat pumps might have reached another plateau at between 150,000 and 200,000 units after 1975.

However, events did change; 1975 saw a shortage of natural gas, starting in several regions of the United States and spreading to very large parts of the nation. The reasons for this shortage need not concern us here, although it is interesting to note that many analysts have concluded that it was largely a result of the U.S. government policies (low, regulated natural gas prices) and could probably have been avoided.

The gas shortage was addressed by giving residential customers who already had gas hookups priority rights (i.e., high allocations) to natural gas. Industrial and electric utility users of gas were restricted and new gas hookups in the residential sector were severely curtailed. Given the shortage of natural gas, public policy dictated that the residential consumer already dependent on gas for space heating suffer the minimum curtailments, as there was no alternative source of heat.

These developments profoundly affected the market for heat pumps in the United States. In vast areas of the country, heat pumps were no longer competing with gas furnaces in new residential construction. The main competition was electric resistance heating (either electric furnaces or strip heating). The economics of heat pumps had turned around, virtually overnight. In many, if not most, parts of the country the heat pumps suddenly became the most economic space conditioning system.

Adding to the attractiveness of heat pumps during the natural gas shortage was the steadily increasing demand for central air conditioning. This phenomenon, largely due to higher income levels and the benefits of air conditioning in hot areas, had been in progress for many years. (Annual sales of unitary air conditioning grew steadily from somewhat under 500,000 in 1962 to between 2.3 and 2.8 million for every year but one from 1972 through 1981). The demand for air conditioning is clearly beneficial to the sales of heat pumps: the economic attractiveness is increased, as the piping, ductwork,

and chiller are paid for in the purchase of the central air conditioners. The relatively high saturation of heat pumps in new houses in the southern portion of the United States, where the sales of central air conditioning systems are highest, is not surprising considering the relative economic advantage of heat pumps when central air conditioning is in any case desired.

The natural gas shortage persisted from 1975 through 1978. Large areas of the United States suffered restrictions in new gas hookups as late as 1978, when the shortages were finally ending. With this background, the rapid increase in heat pump sales during 1975 and 1978 is not surprising. Total sales increased from 139,000 in 1974 to 160,000 in 1975, 325,000 in 1976, 494,000 in 1977, and 572,000 in 1978.*

Presumably the relatively low increase in sales in 1975 is accounted for by the necessity for the industry to increase productive capacity. However, the industry was able to scale up production very rapidly. Sales in 1978 were over 350 percent of the levels of just three years earlier. They were 700 percent of the sales in 1972, just six years earlier.

An important issue confronting the industry after 1978 was whether—in the absence of a natural gas shortage and, as became clearer in later years, the absence of an apparent threat of future shortages—heat pumps could maintain their market share. The sales data for 1979 through 1981 show that heat pump sales remain high. Sales were 640, 447, and 540 thousand units in these three years. The drop in sales in 1980 is due to the low number of housing starts in that year. From 1975 to the present, heat pumps have captured a very consistent 25 percent of the space heating market in new houses. The end of the natural gas shortage shows no influence on the saturation of heat pumps in the 1975–1981 period.

This overview at the national level gives considerable insight into some of the factors responsible for the success of heat pumps in U.S. markets. However, it does not capture the whole story. Numerous forces are at work that strongly influence the market for heat pumps. To understand the factors affecting future markets, we need to understand these forces. We now turn to the information gained in the nine case studies.

*Most of the sales were in the residential market. In 1978, 485 thousand out of 572,000 heat pumps were sold to the residential sector.

Results of Case Studied: Success in the Market Past Natural Gas Shortages

Table 1 summarizes the information gained in the case studies. In all of these cases, sales of heat pumps were high from 1975 through 1978 and have remained high after the end of the natural gas shortage through the present. In this paper, we are able only to summarize the major reasons for the continued success of heat pumps in those markets after the natural gas shortage had abated throughout most of the nation.

Phoenix, Arizona presents an interesting case, with applicability in many other urban areas that have experienced rapid growth in surrounding suburbs. The moratorium on new gas hookups extended from 1976 through 1979 in Phoenix. During this time, urban development was rapid, with the urban area spreading outward from the center. The result of this growth with no new gas hookups was a ring around many parts of the city which is not penetrated by gas mains. Most new housing

Table 1. Summary of heat pump case studies.

	Historical Gas Permit Moratorium	Gas Distribution Costs
Phoenix, Arizona	Recent	High
Philadelphia, Pennsylvania	Now	Low
Tennessee Valley	Recent	High
Kentucky (Except Owensboro Area)	Recent	High
Maryland	Recent	High
Indiana (Southern & Central)	Recent	High
Cincinnati, Ohio	Recent	Low
Northeast Ohio	Recent	Low

developments are presently several miles from existing gas mains. Thus, the cost of new gas hookups is very high. (The charge for a gas hookup is between $300 and $800, depending on the size and location of the new housing development.) As a result of these new economic considerations, the vast majority of new houses in the Phoenix area are expected to have heat pumps.

Philadelphia, Pennsylvania is a case of a persistent gas shortage combined with a utility, Philadelphia Electric Company (PECO), that has marketed heat pumps effectively. For various reasons, gas availability (and new residential gas hookups) did not materialize in the area as quickly after the shortage as in other parts of the country. Because Philadelphia is not a rapidly growing urban area like Phoenix, this did not give a long-term advantage to heat pumps. Nonetheless, it did permit heat pumps to gain a solid and continuing position in the market. PECO has sound economic reasons to promote heat pump sales: a surplus of generating capacity and a high summer peak (providing an incentive to increase winter demand). The utility has combined an extensive heat pump marketing activity with a special winter heating rate that is 3 cents per kilowatt hour below summer rates. For customers who install or replace a central air conditioner, heat pumps are very attractive under these conditions. The utility is particularly eager to see add-on heat pumps using existing gas or oil furnaces as backup systems, as this configuration improves the electric load factor (but causes peaking problems for the gas utilities). As a result of these circumstances, heat pumps capture about 50 percent of the new residential heating market in the PECO service area.

Tennessee has three factors favoring heat pumps:

(1) memory of severe impacts of the gas shortage;
(2) a Federal electricity generating entity, the Tennessee Valley Authority (TVA) eager to promote heat pumps for many of the same reasons as PECO;
(3) low electricity rates, because of low-cost TVA power.

Furthermore, the climate in the TVA area (extending beyond the state of Tennessee) has sufficient cooling loads to provide markets for air conditioning and heating loads to justify the use of a heat pump in winter. Even without special winter heating rates, the economics in the TVA area are relatively favorable to heat pumps.

Iowa illustrates another situation favorable to heat pumps. The state is primarily rural, and natural gas is not available in rural areas. Thus, electric heat pumps compete with high priced propane fuel. Heat pumps have a competitive advantage against propane in addition to providing air conditioning.

The remaining case studies are not discussed in this paper, as they represent various combinations of factors identified in the first four case studies. It is important to recognize that the various factors influencing the market for heat pumps in these case studies are found, albeit in different combinations and of differing importance, throughout the United States. (The major exception to this statement is the colder (northern) portion of the United States, where the performance of commercially available heat pumps has not yet made them widely marketable).

Prospects for the Future

At first glance, it is somewhat surprising that residential heat pumps have been able to maintain their substantial market share after 1976, when the natural gas shortage in the United States ended. Because of higher first costs, heat pumps do not have favorable economics when compared with gas furnaces in almost all regions of the United States. (If a house does not need central air conditioning, then heat pumps are very expensive compared to gas furnaces. However, because of higher first costs of heat pumps compared with gas furnace/central air conditioning systems and the relative costs of electricity and natural gas for heating, the annualized cost of a heat pump system is higher in most parts of the country than that of a gas furnace/air conditioning system.)

Nonetheless, for the factors identified above, we believe it is likely that heat pumps will retain their market share. We believe the rural areas and suburban areas without gas mains, like Phoenix, will continue to be growing markets. We are convinced that those electric utilities which stand to benefit from heat pump sales will be an important instrument for marketing heat pumps, both through direct marketing programs and preferential rates, where permitted by regulatory agencies. The importance of these utility programs should not be underestimated, as the utilities have been potent actors in the space conditioning market. (We estimate that as many as one third of U.S. utilities would clearly benefit from increased sales of heat pumps.) Central air conditioning sales are expected to remain strong. Furthermore, the sales of heat pumps over the past decade will open up a large replacement market for heat pumps.

When we combine these market factors with a heat pump industry that has a strong marketing apparatus of its own, we conclude that the industry

is likely to hold (or possibly increase slightly) its share over the next five to ten years, in the absence of surprises in the price and availability of energy. Over the longer term, the higher price escalation of natural gas will eventually benefit heat pumps, if costs and efficiency improvements of heat pumps and gas furnaces are comparable.

PLANNED ACTIVITIES FOR FY 1986

In FY 1986, we will expand the case studies, gather more quantified data in a number of additional regions, and then commence the modeling during the current and next fiscal years. The challenge facing this work is to do better than the hypothetical analyst in 1972, who was totally misled by historical data on heat pump sales. A major issue is whether rigorous modeling is able to give more credible answers about future sales of heat pumps than we can do at present, given the information from the case studies and the national data. In any case, we are convinced that a meaningful model of heat pump penetration needs to properly account for many factors—in addition to the direct economic data—that influence sales of heat pumps. The exercise we are involved in is thus a serious effort to build a model that departs from (or, from another point of view, extends) the traditional economic approaches to forecasting the market penetration of products.

Validation of the LBL Residential Hourly Demand Model*

H. Ruderman, G. Verzhbinsky, and M.D. Levine

For the past few years, we have been developing a model of hourly and peak residential electricity demand in utility service areas. The model enables us to examine the effects of various energy conservation policies on utility load shapes. Changes in peak load and load factor can affect the financial picture of an electric utility by reducing or increasing the need for new generating capacity. Knowing how conservation policies affect electricity sales and load shapes is crucial for understanding whether utilities will support the policies and assist in their widespread adoption. Application of the model to two utility service areas is described in another article ("Economic Impacts of Residential Conservation Programs on Electric Utilities") in this report.

The model operates by disaggregating projections of annual residential electricity consumption for 12 end uses to each hour of the year. The disaggregation is accomplished with the aid of hourly load profiles for the temperature-insensitive end uses and by fraction-in-use matrices for the temperature-sensitive end uses. The latter contain data on the fraction of the installed appliance capacity in use for each hour of the day, versus temperature or a temperature-humidity index. At present, the annual consumption projections are provided by the ORNL/LBL Residential Energy Use Model.[1,2] Because of the high level of disaggregation in both the hourly and annual consumption models, utility and government policies targeted at specific appliances and building characteristics can be evaluated. Details of the construction, operation, and validation of the residential hourly and peak load model may be found in an LBL report.[3]

ACCOMPLISHMENTS DURING FY 1985

Work this year was primarily directed toward (1) adding a new heat pump module, (2) calibrating and validating the model, and (3) completing the documentation.

New Heat Pump Module

This year, we wrote a new module to calculate heat pump loads in the heating mode. The key part of this effort was an analysis of the difference in performance of heat pumps and electric resistance heaters. Using the DOE-2 program, we simulated hourly electricity loads in residential buildings heated by heat pumps or resistance heaters in four locations: Detroit; Washington, DC; Phoenix; and Minneapolis. For each location, we recorded the heat pump electricity demand for heating for each hour of the year in a matrix by hour of the day and outdoor dry-bulb temperature. Each element in the

*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.

matrix represented the average heat pump demand for the corresponding hour and temperature. We constructed a similar set of matrices for the operation of electric resistance heaters under the same conditions. Dividing each element in the heat pump matrix by the corresponding element of the resistance heater matrix gives a matrix of heat pump efficiencies.

In examining these efficiency matrices, we noticed that they were nearly the same for all locations, except for missing elements in the warmer locations that represented combinations of temperature and hour of day that did not occur. Furthermore, there was little diurnal variation in the efficiency. Thus, we concluded that the average heat pump efficiency depended only on temperature. A code was incorporated in the peak load model to construct the heat pump fraction-in-use matrix by multiplying elements of the corresponding electric resistance fraction-in-use matrix by the heat pump efficiency at that temperature.

The heat pump module was tested by simulating a winter peaking utility based on data from the Detroit Edison Company (DECO). DECO was changed from a summer to a winter peaking utility by increasing the saturation and market penetration of electric heating systems relative to gas and oil systems. With these changes, the peak residential load occurred in January. We compared projections of annual energy use and peak load for space heating for two cases: (1) all-electric heating was supplied by resistance heaters operating at 100% efficiency, and (2) 10% of the electric heating systems were heat pumps with an average coefficient of performance (COP) of 1.88.

The results showed both qualitative and quantitative agreement with what would be expected if heat pumps were substituted for electric resistance heaters. The average COP of heat pumps was higher than the COP at peak load because peaks occur during periods of low outdoor temperature. The average COP calculated from the ratio of annual energy use was 1.89. The peak load COP of 1.13 calculated from the ratio of peak loads was slightly different from the value of 1.11 calculated from the DOE-2 simulations of resistance heaters and heat pumps discussed above. This small discrepancy is due to the normalization to annual energy consumption in the model. We believe these results demonstrate that the module is operating correctly, but the final test will be to compare heat pump loads with measured utility data when they become available.

Model Validation

A major effort took place during this year to validate the LBL residential hourly and peak demand model, using data from DECO. We compared historical residential loads in the service area with the loads calculated by the model. This allowed us to calibrate the model to account for some of the residual demand diversity not included in the original matrices. We used the Detroit Edison service area because this utility provided us with the most complete set of data.

Before comparing the simulated loads with actual measurements, we made adjustments to the data in the ORNL/LBL and peak load models. First, to estimate building thermal integrities, we compared utility data on annual energy consumption for space conditioning with results from the DOE-2 energy model for single-family detached houses. Second, we modified the fraction-in-use matrices for several end uses in order to match the observed daily load shapes.

The data provided by DECO for annual heating and cooling requirements of existing single-family homes are used in the ORNL/LBL and hourly load models. However, DECO did not have data on the heating and cooling requirements of new houses. We used the relative values obtained from DOE-2 simulations, scaled to the data for existing houses, to obtain the annual energy requirements of new houses. We then calculated the ratio of energy consumption for new and existing houses from DOE-2 heating and cooling loads to obtain the thermal integrity factors needed in the ORNL/LBL model.

We made some adjustments to the original fraction-in-use matrices to get better agreement with the historical load shapes. For example, the hourly load curve for freezers contained an obvious typographical error. In another instance, the original curve for clothes dryers showed a sharp dip in energy use during the evening. There seemed to be no obvious explanation for this result, so we increased the load during these hours to give a smooth variation. Another problem was that the load curve for cooking peaked between 6 and 7 a.m. and again between 4 and 5 p.m. Better agreement with measured load shapes was obtained when the cooking curve was shifted 1 hour later.

The most significant change was made in the shape of the miscellaneous load. The original data for this load shape came from single-family homes in Southern California, where the miscellaneous load

varied by more than a factor of 20 from its minimum in the middle of the night to its maximum at 9 p.m. We believe the miscellaneous load varies greatly between service areas because of differences in the mix of appliances that contribute to this component of demand, so that the Southern California data are naturally different from data from residences in the DECO service area. For example, electric swimming pool heaters are commonplace in Southern California, whereas electric blowers on gas furnaces are important in Detroit. Additional research is needed to characterize this end use properly. It may be necessary to further disaggregate the miscellaneous load to reproduce accurately its time and temperature dependence in the model. As a first approximation, we used flat summer and winter miscellaneous loads (taken at the average of the daily load curves). These gave good fits to the hourly load shapes, so we made no further adjustment.

Figure 1 compares the annual residential electricity sales for 1977–1982 in the DECO service area with the results of the ORNL/LBL model. The model results have been corrected for year-to-year differences in weather. We derived unit energy consumptions for space conditioning equipment from DOE-2 runs using a Temperature Reference Year (TRY) tape. We adjusted space heating and cooling annual electricity use for actual weather in proportion to heating and cooling degree days, respectively. The calculated residential sales are about 1% lower than the actual sales over the 6-year period, which gives us confidence that the ORNL/LBL model is responding properly to changes in housing stock, appliance saturation and efficiency, and economic conditions.

A direct comparison of simulated peak residential loads with actual loads was not possible because DECO reports the residential load on the system peak day rather than on the residential peak day. Figure 2 compares the calculated and actual maximum residential load on the system peak day during the period 1977–1982. Except for 1981, the two agree to within 10%. The 1981 point was calculated using a temperature of 98°F from a weather tape for that year. Detroit Edison, however, claims the maximum temperature on the peak day was 92°F, which would bring the calculated load down to about 2400 MW, closer to the actual value of 2185 MW. We are investigating the possibility that we used the wrong weather tape in the calculations for 1981.

Figure 3 shows a comparison of the hourly loads that occurred on the peak days of each month during 1982 with the predictions of the hourly load model after the adjustments described above were made. The agreement is quite good for most months. There appears to be some tendency for the evening peak to be too short and for the early morning minimum to be too low. Because the agreement of the hourly load shape is good over the whole year, we believe the model can accurately forecast load-duration curves as well as peak residential loads.

The largest discrepancy occurs on May 18th, when the temperature exceeded 80°F for the entire afternoon. That the model predicted a load much larger than the actual load may be due two factors, one technical and one behavioral, that it does not capture. First, the model calculates the air condi-

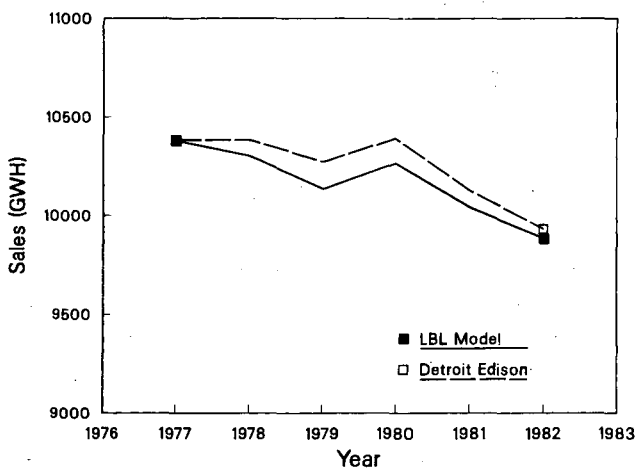

Figure 1. Comparison of annual residential electricity sales, 1977–1982, in Detroit Edison service area with results of the ORNL/LBL Residential Energy Use Model. (XCG 851-7)

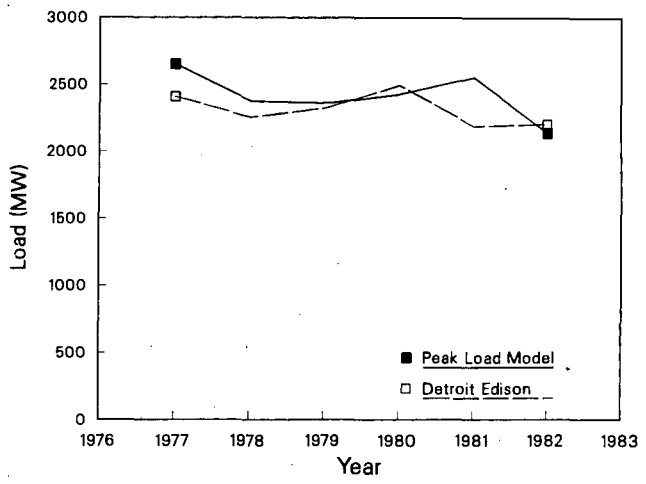

Figure 2. Comparison of the calculated and actual maximum residential loads on DECO's system peak day for each year of the period 1977–1982. (XCG 851-8)

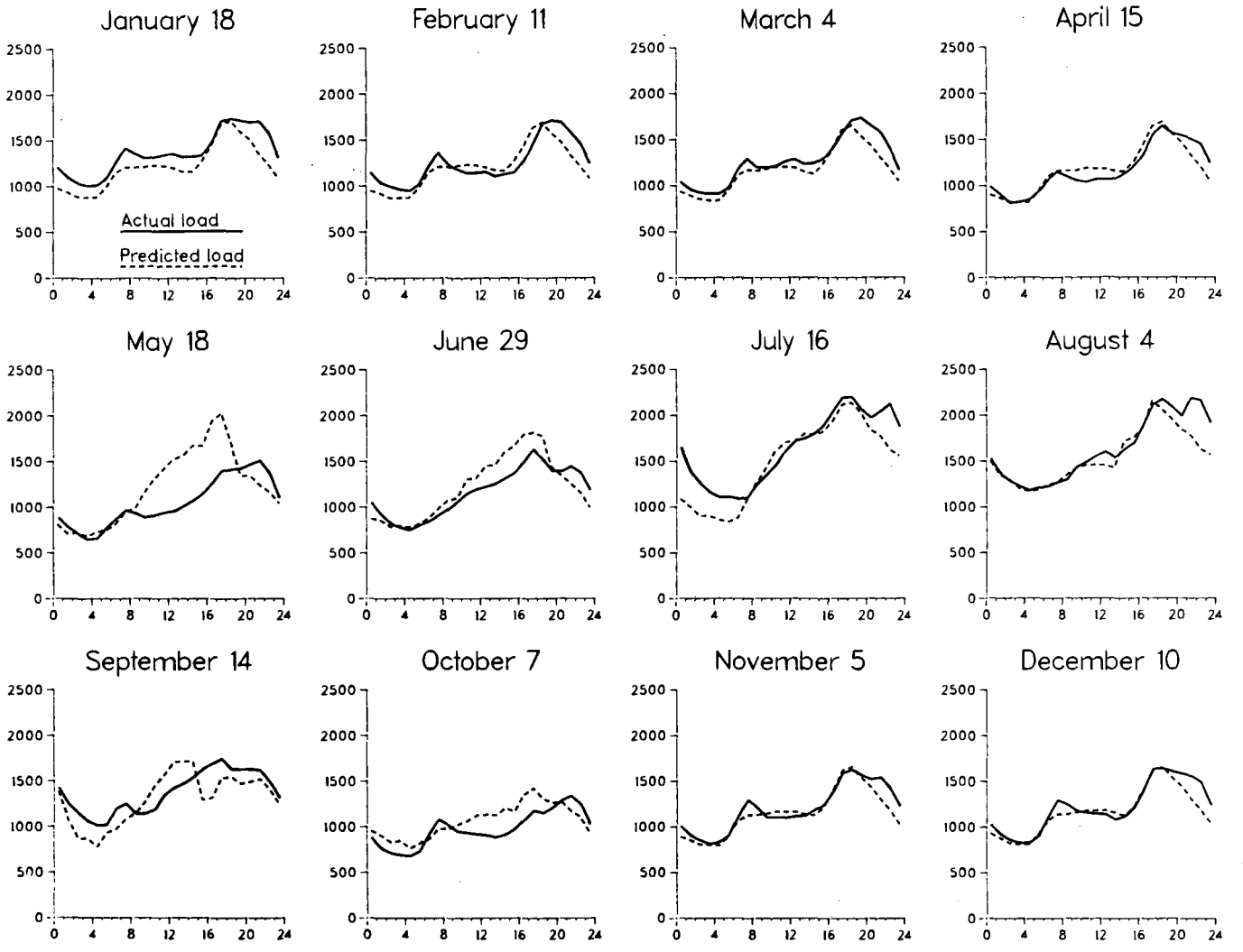

Figure 3. Hourly DECO loads (in MW) on monthly peak days of 1982, compared with predictions of the LBL hourly load model. (XCG 851-6)

tioner load based on the current temperature; it does not explicitly take into account thermal lags. Rather, thermal lags are implicit in the data used in constructing the fraction-in-use matrices. If the days preceding May 18th had lower temperatures so that the heat stored in buildings did not increase as is typical during summer months, then the model, because its matrices are based on typical summer days, would predict too high an air conditioning load. The behavioral explanation is that people do not run air conditioners as much on the first warm day of the year as they would in midsummer, especially if some effort is needed to get them operating after they have been turned off for the winter.

PLANNED ACTIVITIES FOR FY 1986

With the installation of the new heat pump module and the validation of the model, emphasis has shifted from developing the model to applying it to specific utilities. However, we will continue with a low-level effort to correct deficiencies and improve the quality of the fraction-in-use matrices based on our experience in using the model.

With additional funding, we will add the capability to assess the effects of load management and time-of-day pricing on residential load shapes. This task involves building two new modules integrated with the existing module. One, the load manage-

ment module, will modify the fraction-in-use matrices and hourly load profiles on the basis of information about the nature and impacts of specific utility load management programs. The other, a time-of-day pricing module, is more complex, as it involves the assessment of all available data on elasticities of electricity demand as a function of time of day and weather conditions.

The inclusion of time-of-day pricing and load management will yield a model of more general applicability to virtually all major end-use management programs utilities are likely to undertake. The main benefit of performing this work is that its completion will give the model the ability to address a much greater range of utility programs affecting residential loads.

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Market Share Elasticities of Home Heating and Cooling Systems*

David Wood, Henry Ruderman, and James E. McMahon

Concern over future energy demand has prompted several researchers to develop predictive computer models of national energy use. A significant factor in such models is the efficiency of home appliances, in particular space heating and cooling equipment, which account for the largest components of residential energy consumption. An example is the Oak Ridge Residential Energy Demand Forecasting Model,[1] which LBL has modified substantially to create the LBL Residential Energy Model (LBL-REM).[2]

These models require accurate estimates of how the market shares of various fuels (electricity, gas, or oil) or technologies (centralized vs. decentralized systems) change in response to changes in the economy. Thus, estimates of own- and cross-elasticities of market share (with respect to capital costs, operating costs, and income) are commonly found as inputs to the modeling effort. This article describes a new method of developing such estimates.

The unique features of our approach[3] 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. The first three of these features derive from the corresponding aspects of a study[4] by Electric Power Research Institute (EPRI) which we take as a starting point for our work. The last feature is a direct consequence of the manner in which we develop the elasticities, and is exploited in LBL-REM to provide forecasts of future fuel and technology choices by households. Combining these elasticities with existing techniques for forecasting efficiency choice, thermal integrity of the building shell, and usage behavior results in substantial improvement of the forecasting model.

The study by EPRI has two important features which improve upon previous studies of fuel type market share in residential space heating:

1) It uses a database of individual households and actual technology choices to estimate the coefficients of an equation relating the probability of selecting among different space heating technologies to household and geographic characteristics. The average of these probabilities over all households can be taken as the predicted market share of that technology. Summing over technologies of a given fuel type provides an estimate of the market share of that fuel. Almost all previous studies of fuel

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type market share rely on state-level aggregated data, which introduce bias in to the estimates.

2) Each household's choice of heating technology is modeled jointly with the choice of central cooling. Since the cost of heating system chosen (central or non-central) depends highly on the presence of central air conditioning, it seems unwise to model the two choices independently. Statistical cross-tabulations verify that heating system choice is correlated with cooling choice. The EPRI study is the first to model that linkage explicitly.

ACCOMPLISHMENTS DURING FY 1985

Calculation of Market Share Elasticities

Like most previous studies, our method starts from regression equations. (We use slightly modified versions of the coefficients estimated by EPRI.[5] The classical approach to finding elasticities from such equations requires calculating analytic derivatives of market share and using those derivatives (at the mean values of the independent variables) in the formula for the elasticity. This approach has two defects: 1) McFadden and Reid[6] have shown that using only the mean values neglects the variation of the independent variables and thereby introduces bias in the elasticities, and 2) given the technology-specific choices and the nested logit formulation used in the EPRI report, calculating market share derivatives of interest analytically turns out to be so time-consuming as to be judged unprofitable (given the first defect). Instead, we use a "simulation" approach.

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 the new probability under the perturbed conditions of choosing each technology from the regression equation, and determine the change in probability. These changes in probabilities are averaged across households, giving an estimate of the change in market share due to the change in that economic factor. 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. These estimates are approximately quadratic in the perturbation size.

We calculate the arc elasticity as a function of perturbation size for thirteen perturbations (ranging from −33% to +50%) and fit a least-squares quadratic curve to the data. The intercept of this curve (equivalent to a perturbation size approaching a limit of zero) is taken as our value for the point elasticity. A summary of our own-elasticity results can be found in Table 1.

Table 1. Market share own-elasticities for space conditioning equipment.

Equipment	Capital Cost	Energy Cost	Income
Gas Central Heater	−0.38	−0.53	0.07
Gas Non-Central Heater	−1.50	−0.23	−0.57
Oil Central Heater	−1.21	−1.21	−0.30
Oil Non-Central Heater	−1.46	−0.90	−0.59
Electric Central Heater	−0.61	−1.16	−0.15
Electric Non-Central Heater	−0.85	−0.90	−0.26
Central Air Conditioner	−0.20	−0.34	0.30
Heat Pump	−1.77	−0.30	0.38

Modifications to LBL-REM

The LBL Residential Energy Model (LBL-REM) calculates the market shares of each of eight technologies or technology groups, shown in Table 2, below. Note that central electric systems and non-central electric systems together compose the category "conventional electric," and heat pumps are distinct from this grouping. Note also that central air conditioning is possible in combination with any of the other technologies (indeed, it is necessary with heat pumps), rather than being an alternative to them. For the work reported in this article we calculated the arc elasticity as a function of perturbation size for each of these technology groups with respect to a number of explanatory variables. Specifically, we use elasticities of market share with respect to changes in 1) the operating cost of each of the eight technologies, 2) the capital cost of each of the eight technologies, and 3) household income.

As explained in the section above, we can use the quadratic relationship between arc elasticity and perturbation size to estimate new market shares directly, as the consequence of simultaneous changes in a variety of explanatory variables. For perturbations smaller than or equal to +50%, we use the

Table 2. Technology groups

Heating Systems	Cooling Systems
Gas Systems	
1. central gas	
2. non-central gas	
Oil Systems	
3. central oil	
4. non-central oil	
Conventional Electric Systems	Conventional Electric Systems
5. central electric	8. central air conditioning
6. non-central electric	
Non-Conventional Electric Systems	
7. heat pumps (includes central cooling)	

parameters of the quadratic curve estimated on the data. For perturbations greater than +50% (up to +400%), we fit both an exponential and linear model to the data, and select coefficients from the better-fitting model.†

The model stores values for household income and the capital and operating costs of each of the technologies in the "base year" of the simulation (currently, 1977). Operating costs are calculated by the expression

$$OC = \frac{\text{(fuel price)(usage)(thermal integrity)}}{\text{(equipment efficiency)}}.$$

Next we describe a new algorithm for use by LBL-REM in estimating new market shares.

LBL-REM Algorithm for Estimating New Market Shares

The following steps for estimating the market shares of space-heating technologies are carried out for each year of a projection:

1) Calculate "current year" values for:
   a) household income;
   b) the capital cost of eight technologies;
   c) the operating cost of eight technologies, given the new fuel prices, efficiencies, thermal integrity, etc.
2) For household income, capital cost, and operating cost of the eight technologies, calculate:

$$\delta = \frac{\text{new value} - \text{base value}}{\text{base value}}.$$

   Call these δ_{inc}, δ_{CC}, and δ_{OC}, respectively.
3) Use these seventeen values of δ (one income effect, eight capital cost effects, and eight operating cost effects) to find the new market shares of each technology. (See Page 5-74.)
   Note that each of the seventeen values of δ must be tested for $\delta \leqslant 0.5$, and the appropriate linear or exponential expression substituted for the quadratic relationship above when the test is not met.

With this procedure, we are treating the effect of simultaneous changes in all the explanatory variables (income, eight capital costs, and eight operating costs) as being additive in their individual effects. This is accomplished only by a) neglecting all terms of order δ^3 or higher, which seems reasonable if the different perturbations are "small," and b) neglecting cross-product terms of order δ^2, which seems somewhat less defensible.

We can reduce this error somewhat (at least for operating costs) by using the following argument:

†More specifically, we solve two equations: $y = a + b\delta$ and $y = ae^{b\delta}$ for the value of the elasticity at the two endpoints of the range $\delta = 0.5$ to 4.0. To insure continuity with the range where $\delta \leqslant 0.5$, the left endpoint is solved not for the calculated elasticity itself, but rather for the fitted value of the quadratic curve derived on the data where $\delta \leqslant 0.5$. For each of these two equations, the quality of the fit to selected data points in the range can be compared by finding the multiple-r-squared value for each equation. The better-fitting equation is then used to predict new market shares when perturbations are in the range $\delta = 0.5$ to 4.0.

$$MS_{new} = MS_{old}[\ 1 + (\text{income effects}) + (\text{capital cost effects}) + (\text{operating cost effects})\ ]$$

$$= MS_{old}[\ 1 + \delta_{inc}(a_{0,inc} + a_{1,inc}\delta_{inc} + a_{2,inc}\delta_{inc}^2) +$$

$$\left.\begin{array}{l}\delta_{CC}(a_{0,CC} + a_{1,CC}\delta_{CC} + a_{2,CC}\delta_{CC}^2) + \\ \delta_{OC}(a_{0,OC} + a_{1,OC}\delta_{OC} + a_{2,OC}\delta_{OC}^2)\end{array}\right\} \text{terms in first of eight technologies}$$

$$+ \ \ldots \ +$$

$$\left.\begin{array}{l}\delta_{CC}(a_{0,CC} + a_{1,CC}\delta_{CC} + a_{2,CC}\delta_{CC}^2) + \\ \delta_{OC}(a_{0,OC} + a_{1,OC}\delta_{OC} + a_{2,OC}\delta_{OC}^2)\ ]\end{array}\right\} \text{terms in last of eight technologies}$$

Some portion of the change in market share of any given technology is due to simultaneous changes in operating cost of all the other systems. And some portion of the (different) changes in the operating cost of all systems using a given fuel is due to the (common) change in fuel price. If we can capture that portion of the change, we could apply the perturbation δ associated with it against an elasticity that was calculated with respect to fuel price, i.e, with respect to simultaneous changes in the operating cost of all the technologies using that fuel. Essentially, we want to find δ_{fuel} and δ_{tech} such that:

$$\delta_{OC} = \delta_{fuel} + \delta_{tech}$$

where *fuel* refers to new fuel prices (and is common to all technologies using that fuel) and *tech* refers to technology-specific changes in efficiency, usage, etc.

That portion of the change due to changing fuel prices is used in conjunction with an elasticity calculated by perturbing the operating cost of all technologies using that fuel. As such, it is free of any error caused by neglecting the second-order terms in the product of various perturbation sizes for various operating costs. Only the technology-specific changes δ_{tech} carry that error. However, this procedure of dividing δ_{OC} into two parts carries its own error.

We are essentially obliged to trade off between these two sources of error. If we treat the effect of simultaneous changes in several variables as being additive in their individual effects, we make an error due to neglect of some second-order terms. Breaking up the change in operating cost into two parts (in the calculation $\delta_{OC} = \delta_{fuel} + \delta_{tech}$), avoids that error for the "fuel price" portion of the change. Unfortunately, this calculation also requires that we neglect a different second-order term, this time in the product $\delta_{fuel} \cdot \delta_{tech}$.

There seems to be no practical way out of this dilemma. Treating multiple effects other than additively leads to the requirement of calculating elasticities in all possible combinations of variables that might be perturbed, a combinatorial problem that is unpleasant to contemplate, let alone carry out. Otherwise, we wish to choose a procedure which will make the neglected terms as small as possible. In the procedure we propose to use (which ignores the common fuel price effects), the neglected terms are second-order products like $\delta_{1,OC} \cdot \delta_{2,OC}$, where $\delta_{i,OC}$ refers to the perturbation in operating cost of the ith technology, and perturbations are the net of changes in fuel prices, efficiencies, etc. In the alternative procedure (capturing the common fuel price effects), the neglected terms are products like $\delta_{fuel} \cdot \delta_{tech}$.

Clearly, for economic scenarios in which the operating costs of technologies in a particular fuel type tend to move together (i.e., the change in fuel price dominates the technology-specific changes) δ_{tech} will be small relative to δ_{fuel} and their product will be small. If the scenario involves large technology-specific changes above and beyond the fuel price effects, then their product will be (relatively) large. In particular, if fuel prices tend to increase and technology efficiencies improve correspondingly, then the net change in operating costs $\delta_{i,OC}$ may be very small, while δ_{fuel} and δ_{tech} will be large and opposite in sign. For this scenario, the main algorithm will be neglecting terms in the product $\delta_{1,OC} \cdot \delta_{2,OC}$, while the alternative algorithm will neglect the product $\delta_{fuel} \cdot \delta_{tech}$. The main algorithm will be superior. (We note in passing that in scenarios where fuel prices do not change, both algorithms will produce the same results.)

We believe that scenarios of rising fuel prices and efficiencies are more typical of those planned for modeling with LBL-REM, and so we prefer to use the main algorithm. We also intend to produce a

working version using the alternative algorithm, in order to test the significance of the different estimating procedures.

PLANNED ACTIVITIES FOR FY 1986

These elasticities, and the improved algorithm for calculating new market shares, are being incorporated into LBL-REM and will be used in our ongoing analysis of appliance efficiency standards. Further work includes understanding the role of aggregated and disaggregated modeling in the estimation of market share elasticities.

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Utility Load Shape Impacts of Residential Energy Conservation Measures*

H. Ruderman, P. Chan, and M.D. Levine

The role of utilities in supplying electricity is changing rapidly. No longer are utilities required only to deliver kilowatt-hours to the consumer; now they are expected to supply a broad range of energy services. Utilities across the country have offered rebates for more efficient appliances and granted low- and even zero-interest loans to weatherize their customer's houses. They have been required to implement federal programs—such as the Residential Conservation Service, which provides energy audits for houses—and a wide variety of demand-side programs initiated by public utility or service commissions. Such programs to reduce demand growth affect utility plans for constructing new generating capacity and influence the financial outlook of many companies.

The purpose of this study is to evaluate a variety of measures to reduce household electricity demand in terms of their impacts on annual consumption and load shapes and to compare them across service areas. Load shape change is an important aspect of the assessment of demand-side programs, and one that has received little attention to date. It is the interplay of these two types of effects, combined with the economics of supply and the structure of rates of

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the utility, that results in economic impacts on utilities. Because of the lack of peak charges in most residential rates, most utilities sell peak residential power at prices lower than costs. (The loss is made up in sales of baseload power, either in the residential sector or elsewhere.) Thus, residential conservation programs that reduce peak power more than baseload are, in most cases, desirable for utilities. A much more complete characterization of the economic impacts of demand-side programs can be found in another report.[1]

Using different words, the significance of this study is that it looks at the key issue of the load shape impact of utility conservation programs in considerable detail. The absence of such analysis among utilities for many (or most) of their conservation programs has led to an underestimation of the benefits of those programs that have a favorable impact on load shapes (and, conversely, an overestimation of benefits of programs with unfavorable impacts on load shapes). This study is intended to perform the detailed calculations to estimate load shape impacts for a variety of conservation measures in three locations, as a first step to developing an agenda of conservation programs that are well-suited to particular utilities.

ACCOMPLISHMENTS DURING FY 1985

Methodology

We have developed a methodology for calculating changes in annual electricity consumption and hourly loads in the residential sector resulting from the implementation of one or more energy conservation measures in a utility service area. We used the methodology to evaluate various measures in three service areas with differing load characteristics. We evaluated the measures by comparing their impacts on electricity sales and on peak summer and winter loads. The measures were ranked on the basis of a figure-of-merit related to their ability to reduce peak loads relative to electricity consumption.

We considered five measures to improve the thermal integrity of residential structures:

(1) increasing ceiling insulation;
(2) increasing wall insulation;
(3) installing basement and perimeter insulation;
(4) triple glazing; and
(5) decreasing the air infiltration rate.

A second set of measures involved replacing existing appliances with high efficiency models: central air conditioners with a seasonal energy efficiency ratio (SEER) of 14.0, room air conditioners with a energy efficiency ratio (EER) of 11.5, and refrigerators with an energy factor (EF) of 8.7. In addition, we looked at four combinations of measures. One was to bring all houses in the service area up to current (1981) construction practice and current appliance efficiency levels. The others were to convert all houses to passive solar at three levels of thermal integrity and appliance efficiencies.

To examine the effects of these measures, we chose three utilities that differed widely in their climatic conditions and appliance saturations and other household characteristics. The characteristics of the three service areas are summarized in Table 1.

The Detroit Edison Company (DECO) is representative of utilities located in colder climates with long heating seasons. Normally, DECO is a summer peaking utility because most houses in Detroit use gas heaters. To examine more carefully the effects of conservation measures that affect heating loads, we converted DECO to a winter peaking utility by increasing the saturation of electric space heaters from a few percent to nearly fifty percent. Virginia Electric Power Company (VEPCO) is representative of hot and humid climates with large cooling loads. Sixty-five percent of the households

Table 1. Characteristics of utility service areas, 1981.

	Utility Service Area		
	DECO	PG&E	VEPCO
Financial			
Median Family Income ($1000)	21.0	21.7	19.9
Electricity Price (1975 $/MBtu)	$3.56	$3.26	$3.54
Customers			
Residential Customers (1000)	1599	2468	1239
Saturations			
Electric Space Heat (%)	48.6	12.8	26.3
Central Air Conditioner (%)	21.6	15.1	38.3
Room Air Conditioner (%)	31.0	8.9	26.5
Climate			
Heating Degree Days (65°F)	6551	3664	4247
Cooling Degree Days (75°F)	213	526	501
Annual Heating Hours	4810	3912	4515
Annual Cooling Hours	955	1220	1970
Energy and Load			
Residential Sales (GWh)	18,544	14,381	13,478
Summer Peak Load (MW)	3076	3070	3747
Winter Peak Load (MW)	7804	2347	3275

have air conditioners and run them for an average of 2000 hours per year. The climatic conditions in the Pacific Gas and Electric Company (PG&E) service area are less extreme than in the other two. It has a low air conditioner saturation and a relatively short heating season.

We determined the effects of an energy conservation program on hourly load shapes in three stages. First, we calculated the changes in heating and cooling loads in an individual building incorporating the conservation measure. Second, we assumed that the annual energy consumption by end use was calculated for a case in which all homes in the service area incorporated the particular measure. Finally, we disaggregated the annual energy consumption for each end use by hour of the year using hourly load profiles. We compared these results to a base case that did not include the conservation measure. In this way, we were able to determine the percentage changes in annual electricity consumption and winter and summer peak loads.

Our results on the changes in annual electricity consumption and in the hourly load shapes on the peak summer and winter days were derived as follows. First, we compared the effects of the conservation measures within a single utility service area. In addition, we ranked the measures according to a figure of merit based on their relative effect on base and peak load. Then we compared the conservation measures across the three service areas, pointing out the the differences in their effectiveness. Tables 2, 3, and 4 summarize the savings in energy and peak power produced by various means.

An important parameter in utility planning is the system load factor, defined as the ratio of average load to annual peak load for the entire service area. The smaller the load factor, the more load has to be satisfied by expensive fossil-fuel-burning peaking generators. The figure of merit we have chosen to rank the conservation measures is the ratio of the change in peak load resulting from the implementation of the measure in all residential buildings in the

Table 2. Savings from conservation measures—Detroit Edison Company.

		Summer Peak Day			Winter Peak Day		
Conservation Measure	Percent Annual Energy	Percent Peak Load	Figure of Merit[a]	Rank	Percent Peak Load	Figure of Merit[a]	Rank
Ceiling Insulation R-27 to R-38	2.69	1.23	0.46	6	4.33	1.61	3
Wall Insulation R-11 to R-19	2.47	0.75	0.31	7	3.50	1.42	4
Basement Insulation None to R-10	9.50	−1.78	−0.19	8	11.39	1.20	5
Triple Glazing	2.66	1.44	0.54	5	4.29	1.61	2
Low Infiltration 0.7 to 0.4 ACH	7.82	5.43	0.69	4	14.77	1.89	1
Room Air Conditioner EER 6.72 to 11.5	0.56	6.16	11.07	2			
Central Air Conditioner SEER 7.06 to 14.0	1.01	15.09	14.92	1			
Refrigerator EF 4.95 to 8.7	4.45	3.82	0.86	3	0.62	0.14	6
Current Practice	12.94	3.72	0.29		14.03	1.08	
Current Practice with Night Setback	12.75	3.72	0.29		9.26	0.73	
Passive Solar stock practice	5.88	2.28	0.39		6.89	1.17	
Passive Solar current practice	17.78	6.29	0.35		22.37	1.26	
Passive Solar best available	31.09	32.08	1.03		44.54	1.43	

[a]Ratio of percent peak load savings to percent annual energy savings.

Table 3. Savings from conservation measures—Pacific Gas and Electric Company.

Conservation Measure	Percent Annual Energy	Summer Peak Day: Percent Peak Load	Summer Peak Day: Figure of Merit[a]	Summer Peak Day: Rank	Winter Peak Day: Percent Peak Load	Winter Peak Day: Figure of Merit[a]	Winter Peak Day: Rank
Ceiling Insulation R-19 to R-38	0.81	1.92	2.37	5	1.05	1.30	5
Wall Insulation R-11 to R-19	1.17	2.83	2.41	4	2.24	1.90	3
Perimeter Insulation None to R-10	1.32	0.51	0.39	8	2.08	1.58	4
Triple Glazing	1.15	3.20	2.78	3	2.55	2.21	2
Low Infiltration 0.7 to 0.4 ACH	0.89	1.81	2.04	6	2.48	2.79	1
Room Air Conditioner EER 6.72 to 11.5	0.30	2.87	9.57	1			
Central Air Conditioner SEER 7.06 to 14.0	1.46	13.70	9.40	2			
Refrigerator EF 4.95 to 8.7	9.93	6.43	0.65	7	7.31	0.74	6
Current Practice	6.62	8.78	1.33		6.69	1.01	
Current Practice with Night Setback	6.60	8.78	1.33		6.61	1.00	
Passive Solar stock practice	2.00	6.20	3.10		4.27	2.14	
Passive Solar current practice	8.58	13.29	1.55		10.71	1.25	
Passive Solar best available	16.99	31.48	1.85		19.45	1.14	

[a]Ratio of percent peak load savings to percent annual energy savings.

service area to the change in annual electricity consumption. If the system peak occurs at the same time as the residential peak, there is a direct relationship between our figure of merit and the effect of the conservation measure in the system load factor. In any case, the figure of merit is useful as an indicator of relative effect of the measure on peak and base load.

Impacts on Electricity Consumption and Load Shape

The results to date can be summarized by the following points:

- Air conditioner efficiency improvements are the most effective measures for increasing summer system load factors.
- Reducing the air infiltration rate is the most effective measure for reducing winter peak loads.
- Bringing all houses in the service areas up to current practice would result in significant savings in energy and winter peak power.
- Refrigerator efficiency improvements are more suitable for reducing base load.
- Adding insulation in the basement can adversely affect summer peak loads.
- Night setback of thermostats during the winter has little effect on overall electricity demand and only a small effect on winter peak power.

In interpreting results, it is important to note the assumptions made in doing the calculations. We are

interested in making comparisons of effectiveness among conservation measures and between service areas. To do this, we have examined a hypothetical case in which the conservation measures are applied to all residential buildings in the service area. Thus, our results can be interpreted as the maximum potential savings resulting from implementing the measure. Our values of percent energy and peak power savings depend on the saturation of the conservation measure. The figure of merit is less dependent on both the appliance saturation and the level of implementation of the conservation measure.

In the case of Detroit Edison, we performed a set of computer simulations in which we increased the saturation of electric space heating to nearly fifty percent to emphasize the effects on winter peak loads. Our results on energy and peak power—for winter cases—therefore apply to a hypothetical utility having a winter peak due to electric space heating rather than to Detroit Edison itself. The figure of merit applies to Detroit Edison as well as to the hypothetical utility.

Interutility Comparison

An examination of the load shapes for the peak winter day in the three service areas shows that demand is reduced during all hours of the day by the thermal integrity measures. Demand reduction during the summer varies among service areas and among the various measures. Air conditioning in the PG&E service area is a major portion of the residential load between 9 am and 9 pm. In the DECO and VEPCO service areas, the air conditioning load extends well into the night. One might expect that PG&E would show the highest air conditioner figure of merit, but in fact DECO has the highest because its cooling season is the shortest.

Table 4. Savings from conservation measures—Virginia Electric Power Company.

		Summer Peak Day			Winter Peak Day		
Conservation Measure	Percent Annual Energy	Percent Peak Load	Figure of Merit[a]	Rank	Percent Peak Load	Figure of Merit[a]	Rank
Ceiling Insulation R-24 to R-38	1.36	2.88	2.13	3	2.37	1.75	3
Wall Insulation R-12 to R-19	0.97	1.34	1.39	6	1.72	1.78	2
Basement Insulation None to R-10	2.72	1.51	0.55	7	3.98	1.46	5
Triple Glazing	3.12	5.48	1.76	4	5.00	1.60	4
Low Infiltration 0.7 to 0.4 ACH	2.22	3.44	1.55	5	4.86	2.19	1
Room Air Conditioner EER 6.72 to 11.5	0.89	3.61	4.06	2			
Central Air Conditioner SEER 7.06 to 14.0	3.08	19.28	6.26	1			
Refrigerator EF 4.95 to 8.7	5.22	2.68	0.51	8	2.39	0.46	6
Current Practice	9.10	13.65	1.50		11.12	1.22	
Current Practice with Night Setback	9.01	13.65	1.51		10.62	1.18	
Passive Solar stock practice	4.34	8.70	2.00		7.15	1.65	
Passive Solar current practice	11.19	18.94	1.69		13.74	1.23	
Passive Solar best available	19.17	39.66	2.07		20.95	1.09	

[a]Ratio of percent peak load savings to percent annual energy savings.

PG&E has a smaller space conditioning load than the other two utilities, so it shows the lowest annual energy savings due to the thermal integrity measures. This is also reflected in the fact that refrigerator improvements provide the largest energy savings in its service area. For a winter peaking utility, reducing the air infiltration rate is the best way to reduce load factor. Triple glazing is also effective for DECO and PG&E, while wall and ceiling insulation helps for VEPCO. The pattern for the summer peak is less consistent. However, increasing the basement insulation could adversely effect the system load factor in some service areas.

In all three service areas, bringing houses up to current practice would reduce the winter peak load and electricity demand. These effects are largest in the DECO service area. Although night setback changes the daily load shape during the winter, it has no impact on overall electricity demand and very little on the winter peak.

Passive solar construction practices by themselves (e.g., just moving all the windows to the south wall, adding thermal mass, etc.) have relatively small savings. However, combining them with thermal integrity and appliance efficiency improvements results in substantial energy and peak power reductions. It is interesting to note that the effects are roughly linear: if you add the savings due to current practice to those due to passive solar, you get fairly close to the passive solar with current practice savings.

The effects of passive solar construction differ among the service areas. In a winter peaking utility, such as our modified Detroit Edison, the major impact is the reduction of winter peak load. In a utility with a large air conditioning saturation, such as VEPCO, it is summer peak load that shows the largest reduction. Promoting passive solar housing appears to be a good way for a utility to ameliorate its load growth problems.

PLANNED ACTIVITIES FOR FY 1986

Most of the analysis on this project was completed during FY 1985. During FY 1986, we will be evaluating alternative formulations for the figure of merit to select the one that best characterizes the financial impacts on a utility. We will write a paper to be submitted to a referenced journal.

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Impacts of Proposed Changes in the Federal Tax Code on Renewable Energy and Cogeneration Projects*

E. Kahn and C. Goldman

The development of certain cogeneration and renewable energy technologies has been influenced by favorable federal and state legislation enacted in the late 1970's. The legislation provided subsidies for either the investment in, or output from, specific renewable technologies. In addition, the Public Utilities Regulatory Policies Act of 1978 (PURPA) created a market for electricity from such projects by requiring utilities to purchase their output at avoided cost. As a direct result of these policies, several renewable energy technologies and industrial cogeneration have experienced accelerated development. The status of current renewable energy incentives changes significantly at the end of 1985 as all renewable energy investment tax credits expire. Key provisions of the *President's Tax Proposals to the Congress for Fairness, Growth, and Simplicity* also affect renewable energy and cogeneration projects.[1] The most significant provisions are:

- repeal of 10 percent investment tax credit
- lower corporate and individual tax rates
- replacement of accelerated cost recovery system (ACRS) with capital cost recovery system (CCRS)
- non-deductibility of state taxes on federal income tax returns
- institute an alternative minimum tax for corporations

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This article discusses the impact of the President's Tax Proposals and the scheduled expiration of energy investment tax credits on eight selected energy projects.

ACCOMPLISHMENTS DURING FY 1985

Methodology

Projects were selected that were representative of the best technologies currently available and that had high expected returns under current tax law.[2] They are actual projects either in operation or in the advanced development stage. We attempted to simulate the criteria investors would use when deciding to undertake renewable energy or conservation projects. Spread sheets of project revenue, cost, and tax data were developed for each project. Cash flows were projected out to 1997, the last year for which we have a reliable forecast of electricity prices (as indicated by utility standard offers to purchase electricity at fixed prices). We then estimated the investor's after-tax internal rate of return (IRR) under several scenarios:

- current law (before December 31, 1985)
- current law (after 1985) and
- the President's Tax Proposals.

The internal rate of return is calculated from the after-tax net equity cash flows (ATNEC) in each year. ATNEC includes pre-tax income plus depreciation plus any tax savings (or liability) minus equity funds and debt principal repayment. By convention, negative taxes are assumed to be tax savings to investors from net operating losses generated by the project. By analyzing changes in the profitability of these projects, we were able to develop an initial assessment of how currently scheduled and proposed revisions in tax law will affect the development of these and similar renewable energy and cogeneration projects.

Results

The impact of the President's Tax Proposals on the investor's leveraged rate of return is shown in Table 1. Uniformly, the President's Tax Proposal lowers these returns. However, returns on cogeneration projects are still quite favorable (24–26 percent) and the President's Proposal tends to reinforce its emergence as the dominant small power technology.

After December 1985, with the expiration of the energy tax credits (ETC), very high investor rates of return disappear for wind turbines, small hydro, geothermal and wood-fired electricity. The effect is most dramatic for wind-turbines and small hydro. With interest rates at 14 percent, the equity returns on these projects fall to a level that is unlikely to attract much capital. Although returns are much lower under the President's proposal, the yearly cash flows are less variable than under current law (see Fig. 1.) The repeal of the alternative fuels production credit (AFPC) has a very adverse impact on the landfill gas recovery project, as evidenced by the drop in the rate of return from 27.5 to 8.8 percent. This project is analyzed on an all-equity basis. The sponsor's minimum return requirement is 15 percent on this basis; hence the project is no longer viable. Geothermal and wood-electric projects are still financially viable under current law after 1985.

Rates of return on equity for the five renewable energy technologies are in the 7 to 15 percent range under the President's proposal. It is unlikely that

Table 1. Rate of return on equity for selected projects.[a]

	Geothermal[b]	Gas-fired Cogeneration	Coal-fired Cogeneration	Landfill Gas[c]	Wind	Small Hydro	Wood-Electric
Current Law	0.391 (0.54)	0.412	0.402	0.275	0.472	0.274	0.260
Current Law after Dec. 31, 1985	0.226 (0.33)	0.412	0.402	0.088[d]	0.140	0.144	0.195
President's Tax Proposal	0.093 (0.17)	0.242	0.265	0.097	0.122	0.072	0.148

[a]The geothermal, cogeneration, and landfill gas projects are corporate-financed, whereas the wind, small hydroelectric, and electricity from wood waste projects are financed by limited partnerships.

[b]IRR in parentheses is for geothermal project without transmission costs.

[c]All equity.

[d]Assumes Alternate Fuels Production Credit (AFPC) is repealed.

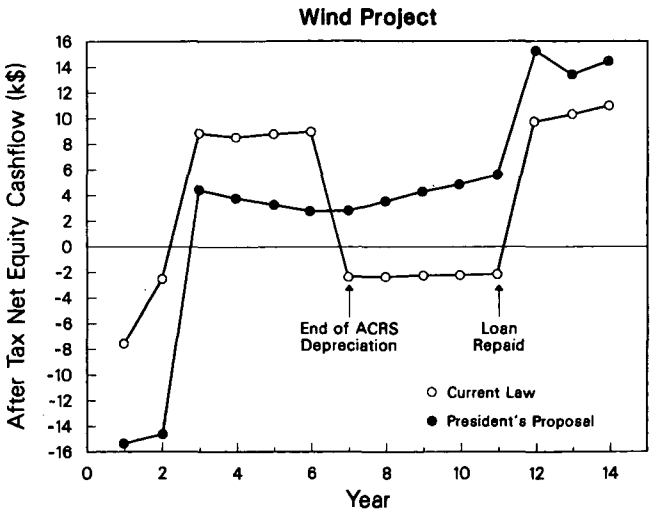

Figure 1. After tax net equity cash flows until 1997 for a wind turbine project under current law and the President's proposal. (XCG 8510-474)

projects with such returns could attract capital since the IRR on equity is at or below the cost of debt. However, a geothermal project unburdened by the need to provide transmission facilities would fare somewhat better.

The analysis of selected projects gives a characterization of the change in returns associated with various tax regimes. These changes do not constitute a forecast of the market for such projects. In this study, we developed a methodology that illustrates how results from a financial analysis of representative projects can be extended to develop a forecasting approach to the market for renewable technologies and cogeneration. We assumed that investment will occur if a project meets the "hurdle rate," some specified minimum rate of return target. The hurdle rate must be greater than the cost of debt to compensate for the added risk. We believe that the hurdle rate lies somewhere between 15 and 20 percent return on equity capital. We then attempted to estimate and quantify endogenous project variability (e.g., distribution of technical and cost characteristics) and exogenous sources of risk (e.g., deviations of input fuel costs or output product prices from their expected level) in order to develop a distribution of returns on a family of similar projects.

We applied this approach to two of our typical projects, wind turbine generators and large-scale gas-fired cogeneration. The single most uncertain variable associated with wind turbine technology is its technical performance. How much output can wind turbine machines produce? The distribution of technical characteristics, which is of most interest for gas turbine cogenerators, does not involve performance uncertainties, but rather capital cost and sizing issues. These applications occur in industrial process activities, where the precise mix of power production to steam use can be quite variable. The coefficient of variation is lower for the cogeneration project than the wind turbine project, which suggests that the returns for these type of projects are less variable.

PLANNED ACTIVITIES FOR FY 1986

Although work on this was completed during the past fiscal year, related research in the following areas is necessary in order to translate change in investor returns on selected projects into a forecast of the market for such projects:

- analysis of the distribution of technical characteristics
- a national survey of avoided cost prices
- examination of issues related to technical progress
- analysis of the sensitivity of the results to macro-economic factors (e.g., interest rates).

Improved forecasting capability does not depend equally on all these efforts. The most important issue is the availability and analysis of market data on the nature of projects within a given technology. We plan to pursue these research areas in FY 86 depending on funding availability.

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A Decade of U.S. Energy Policy*

M. Levine and P. Craig†

In 1965, a high level governmental committee reported that "no grounds exist for serious concern that the Nation is using up any of its stocks of fossil fuel too rapidly; rather, there is the suspicion that we are using them up too slowly...rather than fearing a future day when fossil-fuel resources will be largely exhausted..., we are concerned for the day when the value of untapped fossil-fuel resources might have tumbled...and the nation will regret that it did not make greater use of these stocks when they were still precious."[1]

At about the same time warnings were appearing that U.S. oil and gas production would soon peak.[2] At the time few took them seriously. Yet the predictions have since turned out to be remarkably prescient. U.S. natural gas production peaked in 1973 and had been dropping since. Oil production in the contiguous United States peaked in 1970, and it too is declining. More recently oil from the North Slope of Alaska has come on stream, thus holding total U.S. production roughly constant in recent years. These developments provided the best support in the early 1970's for the idea that the United States and possibly the world were entering a period of decline in the growth of oil supply over the long term.

In December 1973, in the middle of the Organization of Arab Petroleum Exporting Countries (OAPEC) embargo and only months after the Yom Kippur war of September 1973, the Nixon Administration issued the "Dixy Lee Ray" report on energy R&D. The report, commissioned in the summer of 1973, included a figure showing oil imports to the United States—then about 6 million barrels per day (mmbpd)—dropping to zero by 1980.[3] President Nixon stated that "by the end of the decade we will have developed the potential to meet our own energy needs without relying on any foreign energy sources."[4] Events proved otherwise. Imports increased to more than 8 mmbpd, then dropped due to conservation and a slumping economy (though hardly at all due to the new supply technologies which were the dominant focus of the Ray report) to about 3 mmbpd. Today, total self-sufficiency is neither in sight nor a national goal.

The year 1973 is remembered primarily for the oil embargo and the "seven day war" between Israel and Egypt. This was also the year, however, in which the Texas Railroad Commission—responsible for allocating ("pro-rationing") oil production among Texas producers, found that even at 100% production it was no longer possible to meet national demand. Thus, in 1973, it became technically possible for foreign producers to dominate world oil prices. That this possibility existed in 1973 was known to some. That the shift of power to OPEC could occur so rapidly was a surprise to almost everyone—probably including the OPEC nations themselves.

Energy policy in the 1970's was characterized by remarkable complexity, with innumerable twists and turns of policy, attitudes, and beliefs. In 1973, the nation became aware of its growing energy vulnerability. Crash efforts were mounted to develop new energy technologies. Legislation was passed in abundance. An army of people (including ourselves) became instant energy experts. The federal energy establishment was constantly being reorganized. Despite the continuing confusion, most participants felt themselves a part of an important process having vital implications for the nation's future.

By 1981, much of this feeling had dissipated as oil supply was more than ample to meet demand, oil prices eased, and energy issues receded from national prominence. In the course of a short decade the energy problem was transformed (in the public consciousness) from a minor issue concerning a few experts to a major national crisis threatening the Nation and then to one of many issues of some but not overwhelming importance.

ACCOMPLISHMENTS DURING FY 1985

Our aim in this study was to review some of the critical events in the evolution of U.S. energy policy during this eventful "energy decade". While it is too early to write a balanced history of the decade, it is possible to learn a few lessons about the formulation of public policy in response to rapid and distressing changes in price and availability of critical resources. We have chosen to focus on four major areas: (1) institutional change, (2) regulation, energy prices, and allocation policies, (3) energy conservation, and (4) research and development. Each of these areas engages many important aspects of energy policy decisions. A more detailed discussion of the issues presented here is presented elsewhere.[5]

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New Institutions of Government

The embargo and subsequent energy price escalation combined with growing fears of shortages to produce what became a long series of energy "czars" and governmental re-organizations. The Federal Energy Office (FEO) was created to manage the shortage and, after the embargo, to administer price controls. The Atomic Energy Commission (AEC) became the Energy Research and Development Administration (ERDA) under the Energy Reorganization Act of 1974; AEC regulatory functions were assigned to the Nuclear Regulatory Commission (NRC); in 1974 the FEO became the Federal Energy Administration (FEA), the change signifying increasing importance and "permanence" within the federal government. The FEA absorbed the Federal Power Commission (FPC), the agency that had administered natural gas price regulations. New energy programs in solar energy and conservation were started in the National Science Foundation, while older programs in coal housed in the Department of Interior grew in size. All these were moved to ERDA.

As the decade progressed and the national sensitivity to the implications of oil shortage grew, the idea of ERDA, devoted to research and development, grew obsolete. A Cabinet level Department of Energy (DOE) was proposed and approved (Department of Energy Organization Act, 1977). DOE was the product of a national sense of crisis. This new entity brought together staff from many institutional backgrounds, with many persuasions. From the outset the DOE was engulfed in continuing controversy, relating to both its objectives and its managerial competence. Contributing to its problems was an inability to draw upon or to build a national constituency. Among the many problems faced by DOE were the self-induced problem of defining success in virtually every program in terms of "barrels per day of oil delivered." Goal-oriented criteria for success are helpful in virtually any project. The DOE failed to recognize that a goal specified in terms of product delivered is inappropriate to a government agency that cannot itself produce the oil. This type of goal is even more inappropriate when one is often dealing with research and development projects, where the intrinsic nature of the problems renders the goal of product delivery virtually meaningless.

Philosophically opposed to DOE's objectives, the Reagan presidential campaign identified the agency as a candidate for abolition. Today DOE still survives, but internal morale has suffered greatly, and the promise of the organization for national leadership has (for the time being at least) vanished.

Legislation

Energy legislation enacted in the energy decade ultimately included incentives for virtually all energy supply and conservation technologies. There was something for everyone, yet the incentives were not well balanced. The prevailing view was that competition would lead to the best of them flourishing, while the losers would fall by the wayside.

The problem was that incentives, once introduced, are hard to remove. The intangible drilling expenses long enjoyed by the oil and gas business provided a subsidy to that sector not enjoyed by solar. Since political factors made it impossible to remove the existing subsidy, the compromise was new subsidies. By way of example, lobbying by solar groups led to incentives for active solar systems. As chance would have it, Congress at the time was not interested in conservation incentives. Since no one could come up with a good way to distinguish passive solar devices from conservation, only active solar was included—a singularly poor decision from a cost-effectiveness perspective.

The chaos in energy regulation was captured by former FPC Commissioner William O. Doub (1976): "...energy policy making literally resembles a Rube Goldberg production with an abundance of action and few real results...the cost of complying with federal regulations represents about $14 billion annually".[6] A similar gloomy conclusion characterized the government's energy production incentives: "We feel secure in concluding that both past and present energy policy has not had the objective of promoting a more efficient use of our scarce energy resources."[7] And, in a generally optimistic report on the eventual prospects for a synfuel industry in the U.S., Perry and Landsbert (1981) express reservations about the ability of the government to induce this new industry: "This program will either become part of the everyday economy, or it will fail."[8]

These quotations hint at some of the dilemmas posed for the nation in attempting to deal with the "crisis" following the OAPEC embargo. In the largest sense the debate was over the allocation of increasingly scarce resources—the root stuff of economics. Rapid price rises induced by an emergent monopoly and shortages induced in large part from poor allocation programs imposed by our own government led to new incentives, and to new winners and losers. Many of the government regulations were designed to minimize adverse impacts on special groups (e.g., low income weatherization programs and lifeline utility rates intended to protect low income persons from fast-changing energy prices). Other policies encouraged new technologies on grounds that government investment would speed

their entry into the market place. Some (the windfall oil profits tax) were designed to capture some of the unanticipated gains to those who happened to own oil.

The laws with the most profound effects on energy during the decade were those that continued or extended energy price regulations. We thus turn to the subject of price regulation.

Energy Price Regulations

Throughout most of the decade, the federal government regulated oil and natural gas prices. State utility commissions regulated electricity prices. Coal and uranium prices were not regulated.

Oil price regulations originated in the following ways: (1) the Cost of Living Council was in the early 1970's regulating prices throughout the economy in an effort to control inflation; oil, like many other products, was price-controlled and (2) the embargo and subsequent control of world oil prices by a functioning cartel motivated the government to continue price controls on oil long after control on other products were removed.

It is easy to understand the motivations of the government—the rapid increases in oil prices in 1974, combined with the government commitment to reduce inflation and the widespread belief that oil prices greatly contributed to inflation, resulted in oil price controls that became increasingly complex at the decade progressed. Strong political currents also supported price controls; the oil companies were widely seen as gaining enormous profits from the operations of the OPEC cartel. There were powerful popular pressures to keep prices of oil products as low as possible. For example, John Sawhill, Administrator of the Federal Energy Administration under President Ford, was forced to resign his position because of his support for a five cent per gallon gasoline tax. (In 1983, a five cent per gallon tax on gasoline was enacted into law with little controversy or notice.)

Toward the end of the Carter Administration, legislation was passed that gradually phased out oil price controls. A windfall profits tax was included in the political compromise that effected oil price decontrol. The Reagan Administration has taken steps to hasten the process of full decontrol of oil prices set in motion in the previous Administration.

Natural gas price regulation persisted throughout the decade (with the exception of the intrastate market, where prices were unregulated). While there was interest in deregulating prices, the influence of interest groups that benefited from the price controls (especially consumers and pipeline companies that were not vertically integrated) was sufficient to maintain the controls.

The consequences of the price controls were particularly visible for natural gas. A significant shortage in natural gas persisted from 1975 through 1978 throughout large parts of the country. The shortage is not surprising, since the price of natural gas in the interstate market was far lower than that of competing fuels. Partially in response to the shortage, the Federal Power Commission in the late 1970's tripled the price of new gas contracts in the regulated interstate market. There was relatively little outcry at this very large price increase since the price on new contracts could be folded into existing contracts to yield a much smaller increase in average gas prices. Adding transport costs and profits to the selling price of natural gas still left it much lower in price than competing fuels.

The Natural Gas Policy Act (NGPA), passed in 1978, continues gas price regulation until 1985 (or later, for some types of natural gas). The objective of the Act is to allow higher natural gas prices both to achieve greater parity with competing fuels and to spur development of new gas reserves. The NGPA coincided with and contributed to the end to the natural gas shortages. Although the Reagan Administration favors natural gas price deregulation, it has not accelerated the NGPA schedule.

Electricity prices continue to be regulated at the state level. There is little support for deregulation (although reform of the regulatory process is much desired by many groups), primarily because electric utilities are recognized to be a natural monopoly for which price regulation is appropriate.

Important changes have occurred in the areas of wheeling and of marginal cost pricing. The Public Utilities Regulatory Policies Act (PURPA, 1978) requires utilities to wheel power at reasonable prices. PURPA also requires utilities to calculate marginal prices for electricity as a function of time of day, season, and reliability and to pay marginal costs for electricity to any supplier who wishes to sell it. This part of the legislation has had a significant effect on the sources of electricity supply in California, creating a substantial role for small power producers. The chief planning executive of one major utility, Pacific Gas and Electric Company, has gone on record that his company is, for planning purposes, assuming that all additional generation capacity needs will be met by purchases from external sources during the next twenty years.

Lessons Learned

Price regulation that keeps prices down reduces supplies and encourages demand, creating substantial potential for shortages and fostering inefficient and uneconomic allocation and use of energy resources.

The energy decade has, in our judgment, provided very strong evidence of the disadvantages of energy price regulations. While we feel the government has a legitimate role in protecting the population (and groups within the public) from serious shocks outside their control, energy price regulations are not the means to achieve these ends.

Nonetheless, price deregulation remains a complex issue. An important technical issue—the treatment of existing gas supply contracts—is a complicated matter that will be difficult to deal with.

Most analyses of energy price regulation do not discuss issues of economic and monopoly rents accruing to producers. It is a major political issue. At times, substantial portions of the public have accused the oil companies of causing shortages and/or higher prices. Although the evidence does not support this view, the notion that the oil companies have benefited from OPEC is defensible: any major economic actor will attempt to gain from a new and changing economic environment. The more serious analytic issue is the degree to which the public should capture a portion of the economic and monopoly rents derived from oil and gas production. Congress clearly decided that such public capture of these rents was appropriate in passing the Windfall Profits Tax in 1980. Although the Windfall Profits Tax was strongly opposed by the oil industry prior to its passage, it appears to have worked relatively smoothly in the past few years.

In short, energy price deregulation is likely to cause a far more efficient allocation and use of energy resources than regulated prices. Other things being equal, it is also more likely to encourage development of new supplies.

Energy Conservation

During the energy decade conservation grew from nonexistent to a pervasive part of the federal effort. Programs covered virtually every aspect of the economy. A partial listing included:

- mandatory fuel economy standards for automobiles and light trucks, which established progressively tighter fleet average fuel economy requirements for new vehicles from 1978 to 1985
- building energy performance standards for new buildings, designed to reduce energy use for heating and cooling in all new buildings
- residential conservation service, requiring utilities to provide low-cost (subsidized) energy audits for houses
- solar and energy conservation tax credits
- mandatory minimum energy efficiency standards for consumer products (household appliances and heating and cooling systems); energy labels for these products
- funds to support a wide range of state and local activities to reduce wasteful energy use, including support for state energy commissions, energy extension services at universities, and related activities
- grants for low income weatherization, to provide subsidies for residential conservation investments among low income groups
- schools and hospitals program, to provide support for energy conserving capital investments in these institutions
- a federal energy management program that established criteria for energy conservation measures in all federal buildings
- some (albeit limited) consumer information programs about energy conservation
- targets for reductions in energy use in industry

So long as the Nation had a goal of energy independence to protect the public from potentially enormous economic shocks, the actions to reduce demand were easily justified as the easiest and most cost-effective measures in the short run to reduce energy supply pressures.

Energy conservation has proven remarkably successful. One measure is the ratio of economic output to energy input. The Energy to GNP ratio has fallen each year since 1975. The dramatic reduction of energy demand growth during the decade has resulted in reduced vulnerability to the Nation.

A major change in perceptions about energy conservation and the economy took place during the decade. Early in the decade, there was widespread belief that energy and economic growth were inextricably linked: a 3% growth in the economy meant a 3% growth in energy demand. It is now widely recognized that increased efficiency in energy use means that the economy can grow at a rate considerably greater than that of energy demand. Rather than being seen as a threat to the economy, energy conservation is now widely recognized as a means of improving economic performance as well as providing protection from future energy difficulties.

Research and Development During the Energy Decade

The rapid rise in R&D expenditures on energy during the energy decade (up until 1981) diversified R&D activities away from the prior overwhelming emphasis on nuclear energy. The budgets reflect the objective of ERDA (as stated by its two major planning documents, ERDA 48 and ERDA 76) to support a diverse array of projects with the intention that sufficient numbers would succeed and thereby provide protection particularly against vulnerable oil supplies.

The degree of success of the federal R&D is mixed, at best. Judged from the perspective of the Dixy Lee Ray report, and major later planning documents such as ERDA-48 and ERDA-76, achievements are very disappointing. The investment in new energy technologies have not succeeded in establishing new major sources of energy for the country. The expectations that the federal research, development, and demonstration (RD&D) activities would produce in the middle or late 1980's commercial technologies to support new, large, and viable industries were not realized. Technologies to convert coal into liquid and gaseous fuel forms, to extract and process shale oil and possible tar sands, to develop a viable breeder reactor (to assure a virtually inexhaustible source of uranium for electricity), to convert wastes into liquid or gaseous fuels, and to provide solar energy for space heating, industrial process heat, and electricity were seen in the early 1970's as candidates for widespread commercial success in the 1980's.

It is now clear that none of these technologies had a chance for widespread commercial application within a short time. Many of the programs were oversold. R&D contributed very little to increasing energy supplies during the decade. Some key R&D projects did hasten the ability to reduce demand growth by speeding up commercialization of cost-effective energy conserving end use technologies (e.g., energy efficient lighting systems, improved heat pumps and other heating systems).

Much of the RD&D budget was devoted to very large-scale demonstration programs. The large increases in the budgets necessitated some ways of spending money in large chunks. The demonstration programs met this need admirably. They also made fine "pork barrel" projects. Large facilities can be spread around the country, an approach taken for coal conversion facilities.

The research on environmental, safety, and health aspects of energy technologies did achieve some successes during the decade: a considerably improved understanding of measures to improve the safety of nuclear power plants (or, from a different perspective, a recognition of the inadequacies of current design in ensuring safety); increased knowledge about indoor air quality (IAQ) and some control measures; advances in reducing environmental problems of fossil fuel conversion.

The federal budget for energy R&D demonstrate the rapid change in research priorities that has taken place since 1980. Conservation and solar energy research have been slashed to 15 to 20% of fiscal year 1980 levels; fossil energy research is less than 40% of 1980 levels; energy research (high-energy physics and basic research support) has increased by more than 20% in nominal dollars; and nuclear energy and defense-related research have grown very rapidly. Since 1980, the federal involvement in energy R&D has shifted back towards the priorities of the vintage AEC days. Figure 1 displays this vividly. The current budget represents a compromise between the proposals of the Reagan Administration, which had originally committed itself to dismantling DOE and eliminating the conservation and solar—and possibly the fossil fuel—research programs altogether, and Congress, which has acceded only partially to the Administration budget requests and has preserved at least a skeleton of these programs.

Thus, we have seen two dramatic shifts in R&D priorities during a single decade. The approach of

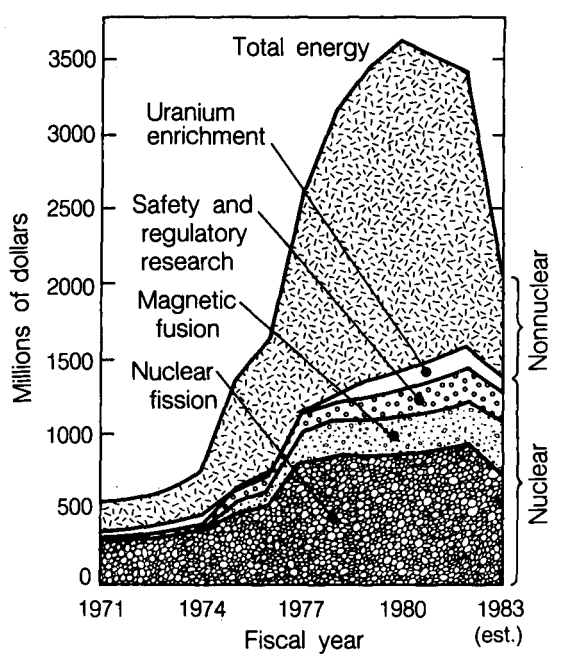

Figure 1. Federal energy R&D expenditures (1971–1983). (XBL 8411-9000)

the 1970's, in which the federal government became involved in virtually all aspects of R&D, has been replaced by a program of greatly enhanced weapons and nuclear energy research, somewhat expanded basic research, and tremendous cuts in research on conservation, solar, environment, and fossil fuels.

Lessons Learned

A major misconception that guided the federal research program during most of the energy decade was the assumption that energy R&D could solve the Nation's energy programs in a short period of time. Not only was the program oversold—to Congress and to the American people—but the overselling led to poorly designed research activities. The government acted as if it believed that it could achieve commercialization of new energy technologies by spending large sums of money. Perhaps the experience of the AEC contributed to this misconception: the federal government had been a major factor in the "creation" of the nuclear power industry and its efforts were crucial in achieving commercialization of nuclear power plant.

In the absence of very large subsidies, new energy technologies can not achieve commercial acceptance until they are cost effective. This is obvious, but was often ignored throughout the energy decade. The demonstration plants to convert coal to liquid or gaseous fuels, the Barstow thermal solar electricity facility, oil shale projects, and the Clinch River Breeder reactor were premature. The technologies are not ready to compete in the market; they do not yield sufficient nonmarket benefits to justify large expenditures on full-scale demonstrations; and they are so unlikely to be picked up by the private sector that the federal expenditures for demonstrations cannot, in our judgment, be justified.

While the government cannot commercialize a technology before it is ready, federal research can be essential to carrying out longer term research to identify new and promising technologies and overcome important technical problems; to treat environmental, safety, and health issues that will not be dealt with by the private sector; and to support small-scale demonstration projects that will enhance the viability of energy technologies that are close to being economic, particularly in risk-sharing ventures with the private sector.

Conclusions

In reviewing the energy decade, we generally found more mistakes than successes. Those who believed in the need for government involvement generally found themselves chastened, while those who believed in R&D were discouraged by the failure of our governmental processes to provide consistent support. For the time being at least, a variety of factors have reduced many of the once "insuperable" energy problems confronting the Nation to manageable size. The same uncertainty in events and factors outside our control will—with certainty—cause unexpected changes in the U.S. energy system, affecting the population in important ways. We do not presume to know what these unexpected changes will be. The energy decade provides a useful basis for assessing a governmental role that can best cope with an uncertain future.

From this complex web of history we would draw some conclusions about government involvement in the management of a critical mineral, during times of real or potential disruption:

- Research and development with a long time to payoff is important for the national good, yet hard for industry to support. There is a continuing need for government to become involved, and to remain involved.
- Government policy to foster energy conservation can provide near- and longer-term economic benefits.
- Government involvement in the energy pricing system and in allocations has been cause for a long series of problems. While there are certainly occasions where such involvement is important—as when there is a prospect for a long term shortage—the major lesson learned is that the problems involved in government intervention are far larger than many people believed, and that the costs of intervention can be substantial.
- The government role is a complex one—as energy is a complex problem. In the face of great uncertainties, considerable care is required to avoid counterproductive actions that respond to immediate political pressures.

PLANNED ACTIVITIES FOR FY 1986

None.

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Analysis of Federal Energy Efficiency Standards for Appliances*

M.D. Levine, P. Chan, J.E. McMahon, and H. Ruderman

In 1978, Congress required the U.S. Department of Energy (DOE) to develop and promulgate minimum energy efficiency standards for all major residential appliances and heating and cooling equipment. Lawrence Berkeley Laboratory's Energy Analysis Program has been deeply involved in the analysis of these standards. The major responsibility of the LBL team has been to assess the benefits and costs of standards to the consumer and to estimate the reductions in energy use that could result from them. DOE decided not to set any standards for appliances. This rulemaking was overturned by a U.S. Circuit Court decision. LBL is now responsible for carrying out over the next several years a reevaluation of the original standards to provide guidance when DOE reissues standards in 1988.

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ACCOMPLISHMENTS DURING FY 1985

Methodology

Our basic approach to evaluating impacts of appliance standards is to estimate the differences between a base-case forecast (i.e., the expected energy efficiency and other parameters when no federal standards are promulgated) and a standards case forecast, in which the energy efficiency and related variables are determined or influenced by the federal policy. If the efficiency of new appliances, appliance usage, first costs, and operating costs were precisely known over the time horizon of the study (as they cannot be) for both the base case and the standards case, then the direct economic impact of the standards on appliance purchasers—the difference between the two cases—would also be exactly known.

Figure 1 presents an overview of the research methodology. The general categories of data required are shown at the left: socioeconomic data for energy forecasting (e.g., projections of housing starts); economic data (demand elasticities); economic forecasts (energy prices); and the economics of appliance efficiency improvements. The model used to project the base and standards cases is a version of the Oak Ridge Residential Energy Demand Forecasting Model (ORNL).[1] This model has been substantially improved for the purpose of analyzing standards.[2] The results of the analysis,

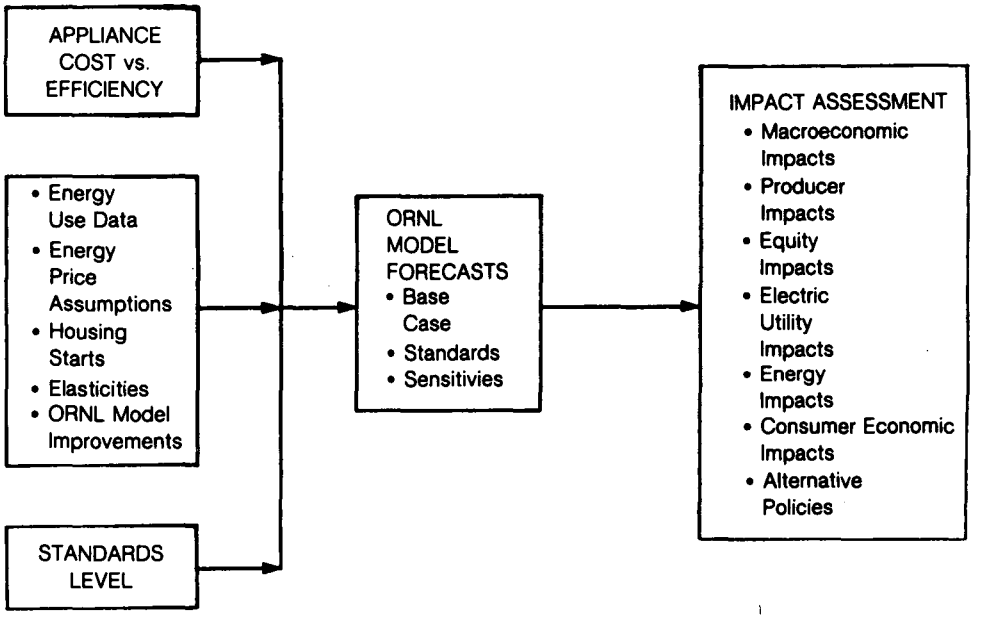

Figure 1. Overview of research methodology. (XBL 845-1963)

shown at the right in Fig. 1, provide direct measures of the impact of standards on appliance purchasers and on the nation: change in energy use as a function of time, change in the life-cycle cost of the appliance over time, net present benefit or cost of the standards to the consumer, and changes in shipments of products resulting from the standards. Impacts on manufacturers and on different groups of consumers cannot be evaluated directly from the model and the data. However, the analysis of direct economic impacts can be combined with other data to obtain estimates of these impacts.

The analysis requires a great deal of data disaggregated by appliance type. Only from such disaggregation can we estimate the retirement rates of individual appliances, the direct and cross price (between fuels) elasticities for energy by end use, and the cost of efficiency improvements for each appliance type.

Key Issues

Some of the most important issues in the analysis of appliance efficiency standards involve the following questions:

- What is the nature of the market for energy efficiency in residential appliances?
- What are the likely impacts of standards on consumers, manufacturers, other interest groups, and the U.S. economy?
- How will the impacts on appliance purchasers vary among income groups and among regions of the country?
- How do the estimated impacts vary with different products, and why? Should a government policy set different criteria for different appliances? If so, on what basis?
- What are the most important sources of uncertainty in estimates of the impacts of standards? How can such uncertainty be dealt with to improve the quality of public policy analysis?
- If standards are promulgated, might their effects be reduced (or even eliminated) by increased usage of the more efficient products? What is the implication of such a "usage elasticity" on the analysis of policy?
- How does the interaction among end uses effect our estimates of energy savings and economic impacts?
- What is the effect on other conservation investments (e.g., thermal integrity)?
- How accurate are the underlying data on cost versus efficiency improvements for the appliances? How can one account for future technological improvements?

Results

Under various plausible assumptions, the analysis projected estimates of energy savings from

the standards that ranged between 11 and 19 quads over a 20-year time horizon, with an expected value of 13 to 15 quads. While 14 quads amount to only about 5% of aggregate residential energy demand over the 20-year period, the impact on energy demand *growth* is dramatic. Figure 2 shows projected residential energy demand with and without standards. The standards originally contemplated by DOE were designed to be within present technological capabilities and to be below life-cycle cost minimums at current fuel prices; if they were to be introduced in 1986, overall residential energy demand growth would be reduced to zero for a decade. Because the legislation provided for updates to the standards, the process could lead to level residential energy demand for two decades or longer. (Other policies or higher-than-expected energy prices could result in declining residential energy demand.)

The total economic impact on consumers is significant. Absent periodic updates to and tightening of the minimum efficiency standards, energy demand is reduced by almost 0.5 quads per year within 6 or 7 years of implementation. At a cost to the consumer of $6 per million Btu, this is a reduction in fuel costs of $3 billion per year. The estimated net present benefit of minimum efficiency standards (fuel cost savings discounted at 10% real, minus the increased first cost of more efficient appliances) is $12 billion, with a range between $10 billion and $16 billion under various alternative assumptions.

Figure 3 shows the estimated energy savings and net benefits of the standards for the six products that consume the largest amounts of energy. Water heaters and refrigerators yield the greatest potential

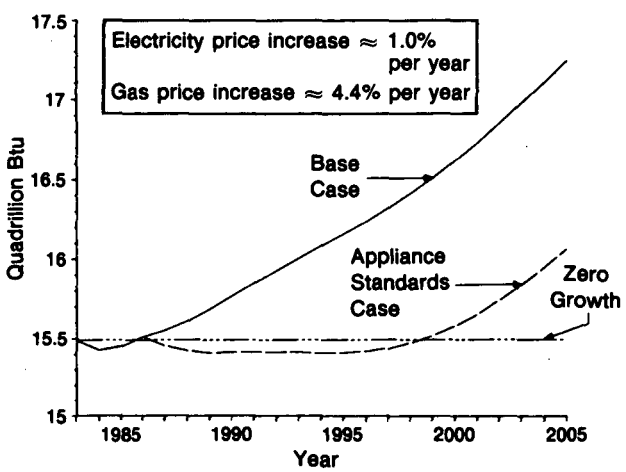

Figure 2. Residential energy demand forecasts. (XBL 845-1966)

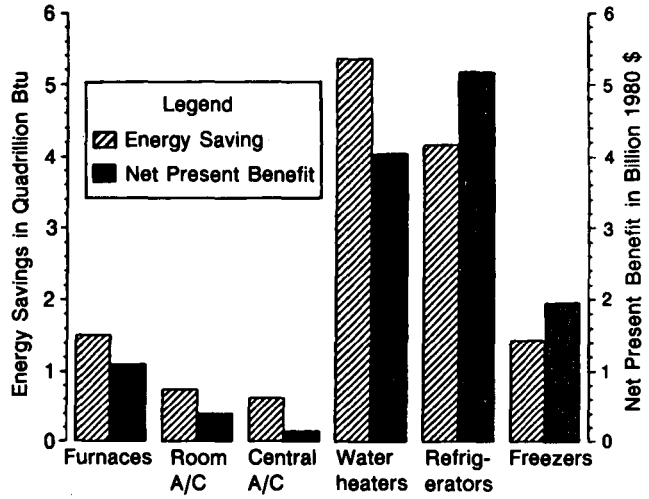

Figure 3. Energy savings and net present benefit of proposed federal standards, by product. (XBL 845-1965)

energy savings. The net benefits are also greatest for these two products, both because the energy savings are largest and because the increased first cost of efficiency improvements are low. Room air conditioners and freezers also yield high net benefits per unit of energy saved.

Standards are estimated to have relatively little impact on furnaces. The major reason is that DOE originally proposed relatively low standards that would have yielded little improvement in energy efficiency over that expected without standards. Since then, condensing furnaces with efficiencies substantially higher than the trial standards have been introduced and are currently selling well. Thus, a tighter minimum standard for furnaces could show substantial energy savings; uncertainty in costs have until recently made the estimation of net benefits speculative.

Central air conditioners show significant energy savings; however, the net benefits are not nearly so great per dollar invested, nor are the unit energy savings as much, as for other products. This is because it is assumed that measures to reduce energy use are added incrementally to existing central air conditioner models, making efficiency improvements relatively expensive. If a full redesign of central air conditioners (and other products) were evaluated, the cost of efficiency improvements could conceivably be different (and lower) than the incremental approach.

Figure 4 shows the projected annual energy savings for several of the most important variables for which we performed sensitivity analyses. The reference or base case assumes a real price escalation

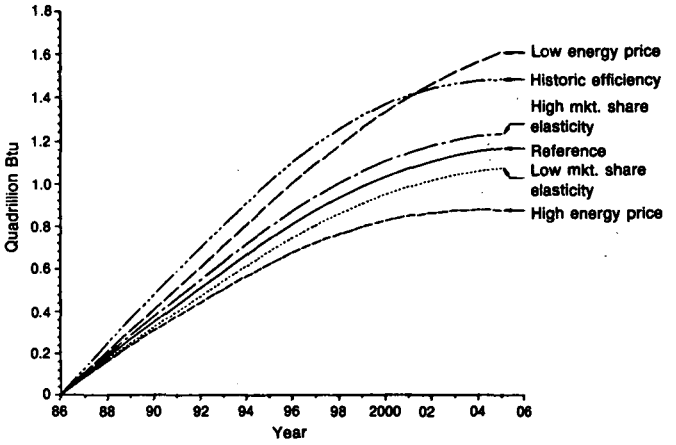

Figure 4. Projections of annual savings in residential energy use under proposed standards for appliance energy efficiency, using various base-case assumptions. (XBL 845-1964)

averaging 4.4% per year for natural gas and 1.0% per year for electricity over a 20-year period. The low energy price forecast assumes real energy price increases of 1.6% per year for natural gas and no increase for electricity. The high energy price forecast is for annual real price increases of 6.1% and 2.0%. The forecast labeled "historic efficiency" does not consider energy prices explicitly; rather, it assumes that, for each appliance, the efficiency improvements of the past decade will continue. The two remaining cases (high and low market share elasticities) make different assumptions about market response to higher energy prices (in terms of the energy efficiency of new product purchases). The results of research conducted to date suggest that the reference case with a constant discount rate may best approximate reality. (This research is discussed in a preceding article on energy efficiency choice by Ruderman *et al.*)

PLANNED ACTIVITIES FOR FY 1986

The reanalysis of appliance efficiency standards will take place over the next two years. Current work at LBL involves (1) improvements to the energy demand forecasting model (particularly in treating various classes of appliances such as frost-free and partially automatic refrigerators); (2) systematic analyses of the strengths and weaknesses of the energy demand model; (3) analysis of energy demand and usage elasticities to improve forecasting results; (4) studies of aggregation issues such as effects of regional climates and fuel prices, and average consumer income; (5) updating market share elasticities for space conditioning equipment choice; (6) improvements in forecasting efficiencies of new appliances; (7) analysis of manufacturers' decisions regarding the energy efficiency of new product lines; and (8) collection and analysis of data on appliance purchases.

Subcontracting will emphasize improved data on the distribution of energy efficiency of appliances sold both nationally and by region of the nation and a preliminary reassessment of trade-offs between cost and energy efficiency in appliances.

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Modeling the Demand for Household Appliances and Energy*

H. Ruderman

The National Energy Conservation Policy Act (NECPA) of 1978 required the U.S. Department of Energy to promulgate minimum energy-efficiency standards for 13 types of consumer products. Standards would be imposed if they were technologically feasible and economically justified. After a considerable amount of technical and economic analysis, DOE decided in 1983 that standards were not justified for any of the products. A Federal Circuit Court overturned DOE's no standards rulemaking in a decision issued in July 1985. NEPCA required DOE to conduct a reanalysis of the appliance standards within five years of their issuance to determine if they should be amended. The Court placed a deadline of August 1988 for a new rulemaking. DOE asked the Energy Analysis Program at LBL to manage the appliance standards reanalysis.

As a first step in the reanalysis, LBL assembled a panel of experts to (1) review the previous standards analysis, (2) recommend changes needed for the reanalysis, and (3) formulate a research agenda to accomplish these changes. This Appliance Standards Analytic Review Group (ASARG) met four times between October 1983 and October 1984 and wrote a report on their findings and recommendations. The ASARG recommended a restructuring of the analysis to better address the legislative requirements and major issues raised concerning the previous analysis. The proposed structure consists of four integrated components (engineering analysis, consumer analysis, manufacturer analysis, and impact analysis) having consistent input, output and assumptions.

The consumer analysis uses models to forecast expenditures for appliances and energy, the number of appliances sold, and the amount of energy they consume. The primary component of the consumer analysis forecasting model is the consumer demand model, which determines the response of households to changes in income, energy prices, equipment costs, and appliance efficiencies. The development of the consumer demand model will take place in four stages: (1) model formulation, (2) data collection, (3) parameter estimation, and (4) testing and validation. When these stages have been completed it can be integrated with the other components of the forecasting model.

During FY–85, the main emphasis of our effort on consumer demand modeling was on the first stage, formulating the model. Some preliminary work was done on evaluating methods of collecting data and estimating the parameters of the model from an existing data set. This article presents an overview of the components of the consumer demand model. A more detailed description of the proposed model may be found in a draft LBL report.[1]

ACCOMPLISHMENTS DURING FY 1985

The consumer analysis addresses the legislative requirements to forecast the economic impacts on consumers and the energy savings resulting from the imposition of standards. In addition, it provides data to the manufacturing and impact analyses. These data include yearly forecasts of appliance sales, equipment costs, efficiency choice, energy consumption, and energy costs. To perform these calculations, we must model the response of consumers to changes in demographic, economic and technological factors. The consumer demand model is thus a critical component in the analysis.

Consumer behavior has a short and a long run component, both of which have to be considered. In the short run, a household can change the amount of service provided by the appliance. Over the long run, a household can replace its stock of energy-using appliances or alter the thermal integrity of the residence. The purpose of the consumer demand model is to calculate household energy use and appliance acquisitions, taking into account these long and short term decisions. Of particular importance for the analysis of standards are the fuel, technology, and efficiency choices.

The consumer demand model has two major components, an appliance utilization model and a technology choice model, which are shown in Fig. 1. The appliance utilization model is used to forecast the short-term response to changes in energy price, income, and appliance and housing characteristics. It also forecasts the longer term capacity, efficiency and thermal integrity changes. The technology choice model simulates household decisions on the acquisition of new or replacement appliances. Included in this model are decisions on fuel, type of equipment, and appliance class.

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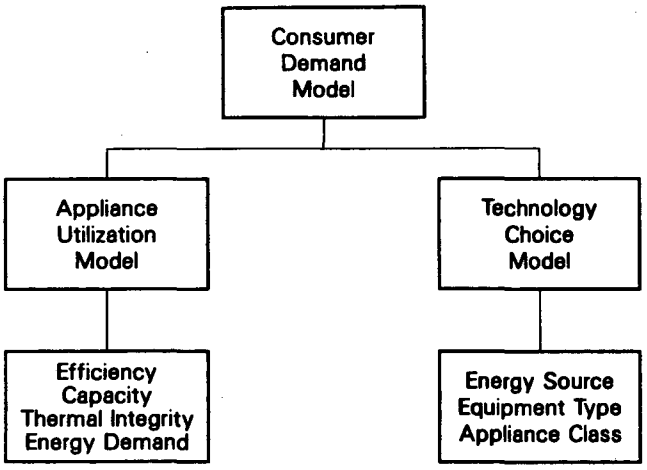


Figure 1. Components of the consumer demand model. (XCG 8511-541)

Consumer demand models will be constructed for the 11 appliance types listed in Table 1. Within each type there may be several classes of appliance. We will discuss the different types under four categories: (1) space conditioning, (2) water heating, (3) refrigeration, and (4) other appliances.

Short-Run Appliance Utilization Decisions

Our approach to modeling end-use energy demand is to consider both the engineering and the economic determinants of demand. We explicitly take into account the engineering factors which cannot be affected by the household in the short run. These are the efficiency and capacity of the appliance and, for space conditioning end uses, the thermal integrity of the residence and weather conditions. Given these engineering constraints, the household decides how much the appliance is used. The utilization decision depends on energy prices and household income as well as the engineering factors. Other factors, such as house size, family size, or occupancy, can influence the demand for certain end uses.

Table 1. Appliance types used in the consumer demand model.

Space Conditioning	
Central Space Heaters	Central Air Conditioners
Home Heating Equipment	Room Air Conditioners
Heat Pumps	
Water Heating	
Gas Water Heaters	Electric Water Heaters
Refrigeration	
Refrigerator/Freezers	Freezers
Other Appliances	
Clothes Dryers	Kitchen Ranges and Ovens

The energy demand model is of the form:

$$E = \frac{C}{e} \cdot \left[\frac{W}{\theta} \right] \cdot h. \tag{1}$$

This is an engineering model which relates the annual energy consumption E by an appliance to its capacity C, efficiency e, and annual utilization h. For space conditioning end uses, there is an additional factor $[W/\theta]$, where W is a measure of the weather and θ is a measure of the thermal integrity of the residence. The economic behavior is in the utilization factor

$$h = h(p, Y, e, C, [\theta,] Z) \tag{2}$$

which depends on energy price p, household income Y, and other household and appliance characteristics Z. This separation of the engineering determinants of energy demand from the short-term behavioral determinants will enable us to study them individually.

Long-Run Capital Stock Decisions

Household decisions regarding capital stock affect energy demand in the long run. These decisions are made when an appliance is purchased for a new home or when it is a retrofit or replacement for a previously owned appliance. The new and retrofit choices are modeled separately because they are made by different agents and have different determinants.

In addition to modeling the household's choice of fuel and technology to provide the end-use service, we have equations for the capacity and efficiency choices because of their strong influence on energy consumption. For space conditioning end uses, we also model decisions about dwelling thermal integrity. Equations for the capital costs of the appliances and thermal integrity are part of the model. Some factors that influence these long-run decisions are climate, house and family size, appliance availability constraints, family income, and energy prices and their anticipated escalation rates.

The model contains long-run capital choice equations for efficiency, capacity, and thermal integrity.

$$e = e(p_o, Y_o, [\theta,] C, K_a, W, Z). \quad (3)$$

$$C = C(p_o, Y_o, [\theta,] K_a, W, Z). \quad (4)$$

$$\theta = \theta(p_o, Y_o, K_\theta, W, Z). \quad (5)$$

Capital costs for purchasing and installing the appliance and the thermal integrity improvements are denoted by K_a and K_θ, respectively. The energy price and income variables have been subscripted to indicate that capital decisions are made at an different time than the utilization decision. We may also want adjust these variables for anticipated price and income escalation. Note that the thermal integrity choice is independent of capacity and efficiency, while the capacity decision is independent of efficiency. This is to ensure there will be no identification problem in estimating these equations.

Two additional equations for capital costs are included in the model.

$$K_a = K_a(e, C, Z) \ . \quad (6)$$

$$K_\theta = K_\theta(\theta, Z) \ . \quad (7)$$

They serve as constraints on the capital choice equations. They can be estimated independently of the other equations using data on appliance prices and the cost of thermal integrity improvements. It may be possible to use engineering equations for the capital costs (e.g., cost versus efficiency curves). The capital costs for some end uses should include installation costs.

As a first approximation, we will assume that the equations for h, C and e are of constant elasticity form. Whether we have to consider more complex forms is an empirical question that will have to be answered by looking at the data. The energy demand and capacity and efficiency choice equations under this assumption are

$$E = A p^{\beta_1} Y^{\beta_2} e^{\beta_3 - 1} C^{\beta_4 + 1} Z_1^{\beta_5} \ , \quad (8)$$

$$e = \overline{B} p^{\gamma_1} Y^{\gamma_2} C^{\gamma_3} Z_1^{\gamma_4} Z_2^{\gamma_5} \ , \quad (9)$$

and

$$C = \overline{C} p^{\epsilon_1} Y^{\epsilon_2} Z_1^{\epsilon_3} Z_2^{\epsilon_4} \ . \quad (10)$$

In these equations, p is the energy price, Y is the household income, Z_1 and Z_2 are sets of household and appliance attributes, and $\beta_1 \cdots \beta_5$, $\gamma_1 \cdots \gamma_5$, $\epsilon_1 \cdots \epsilon_4$ are parameters to be determined. For space heating and cooling, Z_1 and Z_2 will contain variables for climate and thermal integrity. The purchase price of the appliance K is also assumed to have a constant elasticity form

$$K = K_o e^{\alpha_1} C^{\alpha_2} Z_2^{\alpha_3}. \quad (11)$$

Technology Choice

Technology choice includes decisions about energy source (gas, oil or electricity), type of equipment (room or central air conditioner), and appliance class (top, side or bottom mounted freezer, with or without automatic defrost). Since these represent qualitatively different, non-overlapping sets of possibilities, some form of discrete choice model is appropriate.

The discrete choice model is based on the assumption that consumers choose the appliance that maximizes a weighted sum of the consumer and appliance attributes. In addition, there is a disturbance term representing omitted variables or truly random consumer behavior. (This is known as a random utility model.) The weights are the unknown parameters to be estimated, and they may depend on the appliance and the consumer. These assumptions, along with an assumption about the distribution of the disturbance terms, lead to some form of the multinomial logit distribution. The simplest form of the model is

$$P_{ij} = \frac{\exp(\sum_k \beta_{kj} x_{kij})}{\sum_i \exp(\sum_k \beta_{kj} x_{kij})} \quad (12)$$

where P_{ij} is the probability that household j makes choice i, x_{kij} is the kth attribute which may depend on i and j, and β_{jk} is the unknown weight for the kth attribute. More complex nested logit forms that include correlations between end uses are employed in our technology choice model. As an example of a nested logit model, we now describe our model of space conditioning.

Because of their interdependencies, the choice of space heating and cooling technologies will be be modeled jointly. For new residences, we will use a discrete choice model with three levels of decision making. At the highest level is the decision on heating system configuration—should there be a central system, a non-central system, or none at all. The next level of decision is whether or not to install air conditioning. The third level is the choice of space

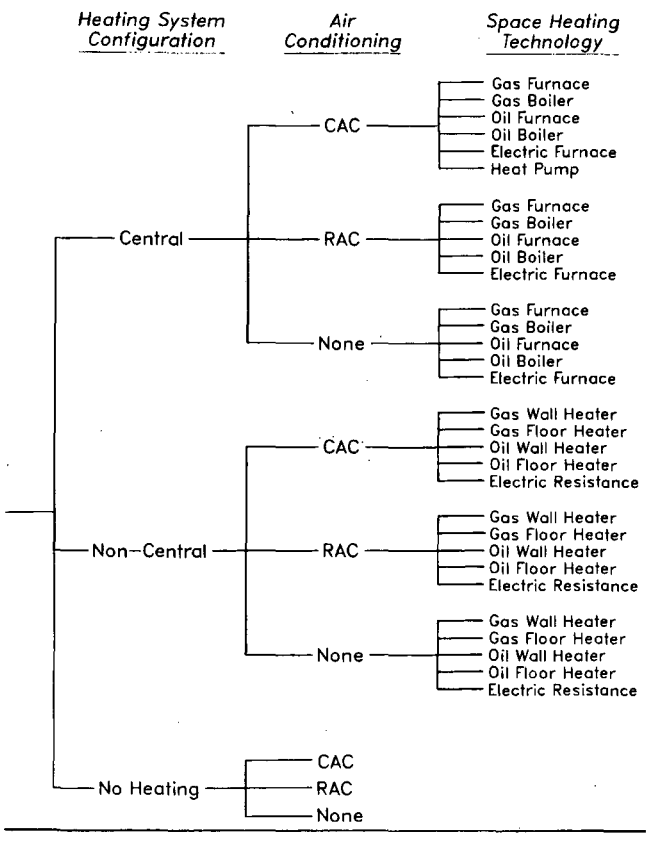
heating system. An example of a decision tree for space conditioning technology choice is shown in Table 2.

The decisions to install a space heating system and whether it is to be central or non-central are made at the time the residence is constructed, usually by the builder. Factors that influence this decision are the size of the building, the climate, the cost of pipes or ducts, and possibly the income of potential occupants. In this type of model, the costs of the heating and cooling equipment affect the decision indirectly through their influence on the lower level decisions.

The second decision, whether or not to have air conditioning, depends on climate, equipment cost, and family income. For central air conditioners, this decision is often made by the builder, whereas for room air conditioners it is made by the occupants. The room air conditioner decision includes the number of units installed, which depends on house and family size.

The space heating technology choices shown in the last column of Table 2 are meant to be representative. The technologies eventually included will be selected after the appliance classes for the central and non-central heating systems have been determined. They will also depend on the amount of effort we want to expend on data collection. At the least, we have to distinguish four fuel types—gas, oil, electricity and other. Space heating technology choice depends on capital and installation costs, maintenance costs, fuel prices, and income. For non-central systems, the decision includes the number of units installed, which depends on house or family size.

Table 2. Example of a decision tree for space conditioning technology.



The formulation of the consumer demand model allowed us to identify the data requirements for estimating the parameters of the appliance utilization and technology choice models. We evaluated existing data sources for the relevant information. There were no sources that contained national household data on appliance efficiency and capacity choice. We decided to use a national survey of appliance purchases by a market research organization and add our own questions to determine the actual appliance that was bought and at what price. This will enable us to obtain a broad range of information on the purchase decisions, including consumer attitudes, perceptions and the purchase process.

As a test of the space conditioning model we made preliminary fits of the appliance utilization model and the technology choice model to data from the annual housing survey. These data were compiled by Cambridge Systematics, Inc. (CSI) for the REEPS Model.[2] CSI assumes efficiencies for various appliances and calculates energy consumption and capital cost (which depends on capacity) using a simplified thermal load model. We made additional calculations under different assumptions about efficiency choice, e.g., minimizing life-cycle costs. Our fits were able to distinguish among these different models of behavior.

PLANNED ACTIVITIES FOR FY 1986

Additional work will be done on the model formulation stage during next fiscal year. Of especial interest will be an attempt to incorporate market behavior variables in the consumer demand model. These would include consumer's perceptions of the attributes of the product (brand name, reliability, price, energy use, and other features) as well as information on the process the consumer went through in making the purchase.

A major effort will be to begin the data collection for refrigerators and possibly at least one other appliance. This will involve adding our own questions to the market research questionnaire. The first step will be to determine the brand name and model

number so we can identify the efficiency and capacity of the model purchased. We will also ask the purchase cost. These are the primary data we need to estimate the technology choice and some of the appliance utilization equations. In addition to the data from the survey, we need to collect additional information on household energy consumption (from utility bills) and weather data to be able to estimate the appliance utilization equation. If the data collection proceeds as planned, the third stage, parameter estimation, will begin.

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Planning for Oil Overcharge Funds: The California Experience*

E. Vine, J. Sathaye, and A. Rosenfeld†

Within the next few years, states will be receiving some of the largest amounts of funds ($3–5 billion) ever released by the U.S. government to be spent on energy conservation and renewable energy programs and projects. The source of these funds is the Petroleum Violation Escrow Account (PVEA). In anticipation of these funds, a PVEA planning process was developed in California to assist the Governor and the State Legislature in allocating the PVEA money. The California Energy Commission selected the Lawrence Berkeley Laboratory (LBL) to evaluate energy projects proposed by state agencies and those generated from public workshops.[1] The evaluation process lasted eight months, from July 1984 to March 1985. We review the evaluation process undertaken in California and present the evaluations of ten energy programs as examples.

ACCOMPLISHMENTS DURING FY 1985

The PVEA is derived from judgements against oil companies (and negotiated settlements with them) stemming from legal actions by the federal government for price overcharges during the period September 1973 to January 1981. The federal government is in the process of collecting and disbursing oil company profits resulting from the violations of federal price regulations. Monies collected and not yet disbursed are held in a Department of Energy (DOE) escrow account.

Decisions at the federal level on how to disburse PVEA funds have been made through a series of court cases, out-of-court settlements between DOE and the oil companies, and one directive from Congress (the Warner Amendment). The most frequently used forms of disbursement have been direct payment to identifiable injured parties (generally larger users, such as utilities) and supplemental funding for state energy programs. Under DOE's Subpart V process (generally used for out-of-court settlements), direct payments to injured parties are made first, with the residual going to the states. Because of the way the entitlements program operated, crude oil overcharges were spread approximately equally among all refiners. For this reason, distributions of PVEA funds from crude oil cases to the states are made according to the percentage of refined petroleum products consumed in each state.

As of November 1985, the federal government has distributed approximately $800 million: $82 million through the Chevron consent order, $200 million through the Warner Amendment, and the remainder through direct payments to injured parties that could be identified by DOE. Two cases pending before the courts, the Exxon and Stripper Well cases, have the potential of providing significantly greater PVEA funds to the states.

The Warner Amendment (Public Law 97-377, or Section 155 of the Further Continuing Appropriations Act, 1983) restricted the use of most of the PVEA funds to supplement current levels of funding in the following five existing programs: Weatherization Assistance Program, Low-Income Home Energy Assistance Program, Energy Extension Service Pro-

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†Energy Efficient Buildings Program.

gram, Institutional Conservation (Schools and Hospitals) Program, and the State Energy Conservation Program. The mechanism and guidelines for the disbursement of future funds are not entirely clear and may be different from those under the Warner Amendment. However, the appellate court decision on the Exxon case (now under appeal to the U.S. Supreme Court) will use the Warner Amendment restrictions for disbursing these funds.

Figure 1 presents the evaluation process undertaken in this project. In 1983, in anticipation of oil overcharge funds, the California State Legislature directed the California Energy Commission (CEC), in cooperation with two other state agencies, to define a scope and select a contractor for studying the energy conservation potential for all possible uses of PVEA funds (California Budget Act of 1983).

The CEC began the evaluation process to assure the broadest possible participation by state agencies and the general public in developing ideas for expenditure of PVEA funds. The actual development of proposals and evaluation criteria was undertaken by an advisory committee to the CEC (the PVEA Working Group) composed of representatives from sixteen state agencies. These agencies represented a wide range of views and concerns related to energy. At the beginning of the process, we organized an evaluation team (the LBL Evaluation Team) to assist in the development of evaluation criteria and in the evaluation of state agency proposals and projects proposed in the public workshops. This team was composed of thirteen individuals from LBL and the University of California (Berkeley and Davis campuses) and four private consultants who had considerable knowledge and expertise in energy conservation and renewable energy sources.

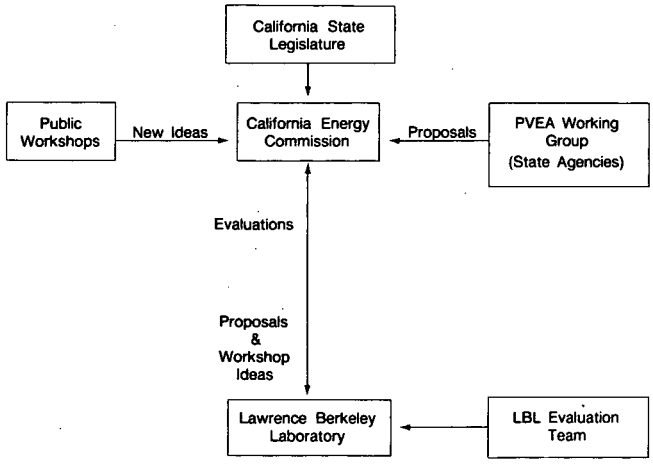

Figure 1. Flowchart of PVEA evaluation process. (XBL 8512-5035)

One of the principal objectives of the evaluation process was to ensure an objective and consistent evaluation of all proposals. One mechanism for achieving this objective was to have all agencies respond to the same criteria, information requests, and assumptions for developing their proposals. The PVEA Working Group first developed evaluation criteria and included a set of instructions for preparing proposals. It agreed to emphasize proposals for generic statewide programs under which actual projects would be selected later through competitive processes. LBL evaluators studied the resulting proposals and often requested additional information from the proposing agencies to develop better and more complete proposals. Members of the LBL Evaluation Team also received explanations and clarifications of these additional information requests. Thus, the evaluation process was an iterative process: evaluators received and evaluated proposals from state agencies, requested additional information and modifications or clarifications to existing data, received additional information, and completed their evaluations of the proposals.

The PVEA Working Group met during a period of more than eight months and considered more than 200 proposals. Proposals that appeared to be premature or unworkable were withdrawn. Several agencies worked together to develop joint proposals and eliminate duplication. Ultimately, 73 PVEA proposals were submitted to LBL for evaluation.

During this period, the CEC conducted a series of statewide workshops for the general public to encourage their participation in the PVEA planning process and the development of their own proposals. The public workshops generated close to 550 proposals from local governments, constituent organizations, and members of the general public. In reviewing the public workshop ideas, we concentrated on identifying important energy opportunities that were missed by the state agency proposals. Based on this review, new proposals were formulated and, in some instances, agencies expanded their proposals to accomodate new ideas. LBL evaluated the public workshop suggestions and allocated the great majority of them to state agency proposals or other public proposals. Drawing from 57 ideas received at public workshops, LBL prepared and evaluated ten new proposals. In sum, a total of 83 agency and public workshop proposals were submitted to LBL for detailed evaluation.

We evaluated the proposals according to sixteen criteria (Table 1). We compared the proposals with

Table 1. Evaluation criteria.

1. Projected energy savings or production, over time
2. Projected direct non-energy benefits, over time
3. Projected cost, over time
4. Cost-effectiveness (societal and leveraged)
5. Leverage of private funds
6. Conformance with U.S. Department of Energy rules
7. Level of expansion over current efforts
8. Monitoring and feedback provisions
9. Minimum level of effort for project to be viable
10. Other programs serving the same clients simultaneously
11. Level of programmatic or technological innovation
12. Plans to continue the project after PVEA funding
13. Likelihood of continued financial obligation beyond PVEA
14. Low-income impacts
15. Environmental impacts
16. Job development

one another based on these criteria, but they were not given an overall ranking. The information collected in response to these criteria was intended to be used by the governor and the state legislature for developing their own priority list of projects to be funded.

The evaluation report examined the criteria in greater depth.[2] However, four criteria deserve special attention. First, in examining cost-effectiveness, we made great efforts to reduce the energy benefits and project costs from each proposal into comparable benefit-cost ratios. We calculated the benefit-cost ratios by discounting future energy benefits and project costs back to their present value (we used a real discount rate of 6%). This adjusts the results to account for the time value of money; for example, at a real discount rate of 6%, a dollar today is worth 1.34 times the dollar amount to be received five years from now. The societal energy benefit-cost ratio includes all costs to implement energy savings measures—both PVEA and participant shares. This ratio indicates the return per dollar spent from the standpoint of the entire economy. The leveraged energy benefit-cost ratio includes only the PVEA-funded costs. This ratio indicates the benefits per dollar of PVEA funds expended.

Second, we made monitoring and feedback provisions an important criterion because many existing energy conservation programs are being implemented without any knowledge of their energy savings and cost-effectiveness. Accordingly, this criterion served as a stimulus for agencies to include monitoring and feedback provisions in their proposal so that better data would be available for managing the programs and conducting program and project evaluations.

Third, the advent of PVEA funds represents an opportunity for state agencies and the general public to develop new and innovative energy programs. Accordingly, the criterion of programmatic or technological innovation served as a stimulus for the development of proposals different from traditional energy programs and projects. In addition, in one of our reports to the state agencies during the initial development of the proposals,[2] we provided innovative energy projects and ideas from nineteen other states.

Fourth, the low-income population was considered to be in need of special assistance based on data indicating that low-income people bear a proportionately greater burden of rising energy costs than other income groups. Accordingly, we prepared a report on the energy characteristics of low-income households in California so that state agencies would attempt to develop programs and projects targeted to low-income groups.[3]

The detailed evaluations of each proposal included information on the above criteria and additional proposal features, such as the kinds of organizations involved in the actual delivery of services ("service providers": e.g., utility companies, industries, state agencies, local governments, schools, consumer groups, and contractors) and the groups that would use the services ("target end users": e.g., low-income households, schools, residential sector, state agencies, businesses, transportation sector, local governments, and agricultural sector).

After preparing detailed evaluations, we provided summary evaluations of each proposal and a large table briefly describing the key characteristics of the proposals that would be relevant for decision-makers. Table 2 of this report presents an excerpt from this table showing ten proposals chosen to illustrate the criteria mentioned above.

Table 2 characterizes each proposal in successive columns, with the following information: (1) title of proposal, (2) service provider, (3) target end-user, (4) new/expansion (whether the proposal is a new idea, or an expansion of an existing project or program), (5) program duration (in years), (6) societal energy benefit-cost ratio, (7) leveraged energy benefit-cost ratio, (8) energy benefits, (9) PVEA funds, (10) matching funds, and (11) participant costs. For the last six characteristics (6–11), categories from "very

Table 2. Example of summary table.

Proposal	Service Provider	Target User	New/[a] Expn.	Program Duration (Yr)	Benefit/Cost[b,c] Soci-etal	Benefit/Cost[b,c] Lever-aged	Energy[c] Saved	Cost (M$)[c] PVEA	Cost (M$)[c] Matching	Cost (M$)[c] Participant[d]
1. Energy program for low-income/ underserved clients	Contractor Local govt.	Low-income Resid.	Exp.	3	M	H	L	5.77(M)	0.18(M)	20.3(H)
2. Irrigation of agricultural land	State	Agric.	New	3	M	M	VL	0.3(VL)	0.07(L)	None
3. Revolving loan fund	State	Business Agric.	New	10	M	H	H	30.0(H)	0.8(M)	127(VH)
4. Fuel efficient fleet maintenance	Local govt.	State Local govt. Transp.	Exp.	3	H	H	M	1.5(L)	0.06(L)	None
5. K-12 energy management centers	County School	Schools	Exp.	3	H	H	M	5.3(M)	0.06(L)	2.1(M)
6. Telecommuting/telework project	Contractor	State Local govt. Business	New	2	L	L	U	3.2(M)	0.03(VL)	None
7. Cogeneration in university and college facilities	State	State	Exp.	3	M	VH	L	1.1(L)	0.18(M)	None
8. Transit bus remanufacturing	Local govt.	Transp.	New	3	L	L	VL	8.0(M)	1.0(M)	None
9. Transportation system management for local government	Local govt.	Transp.	Exp.	5	H	H	M	20.0(H)	None	2.5(M)
10. Home energy rating system	Local govt.	Resid.	Exp.	4	H	H	H	4.0(M)	U	36.0(H)

[a]New idea or expansion of existing project.

[b]Definitions of benefit/cost ratios: Societal ratio = Net energy benefits/(PVEA costs + all other costs); Leveraged ratio = Net energy benefits/PVEA costs.

[c]VL–Very Low, L–Low, M–Medium, H–High, VH–Very High, U–Unknown, Resid.–Residential, Transp.–Transportation, Agric.–Agriculture.

[d]Participant is the same as target user.

low" to "very high" were constructed using the data from the summary evaluations. The projects were grouped into approximate thirds (low, medium, and high). The extreme groups are then subdivided at logical breakpoints (very low and low, very high and high). For benefit-cost ratios, we eliminated the "very low" category in order to identify all projects below 1.00 (a standard economic criterion) as "low." It is important to note that the boundaries between groups are only rough approximations and are used primarily to distinguish groups of proposals (rather than one proposal from another). Hence, in certain instances, adjacent ratings are extremely close and, in light of the uncertainties in quantitative estimates, the differences may be overstated.

In general, we found that certain types of proposals had higher benefit-cost ratios than others due to the nature of their program. For example, energy education/information programs that focused on changing people's behavior typically had minimal costs (especially, if the program infrastructure was already in place) and large benefits spread over time. In contrast, capital intensive projects (e.g., bus remanufacturing) had high initial costs and moderate benefits spread over time. Such projects often had small benefit-cost ratios.

In summary, the process of evaluating energy proposals in California in anticipation of large amounts of oil overcharge funds was characterized by several distinctive features. First, this was the first time in California that all state agencies with energy conservation and renewable energy interests came together to express their views and priorities for developing energy programs. As a result of this interaction, agencies were able to coordinate some of their current programs and to cooperate in joint ven-

tures in the planning and possible utilization of the oil overcharge funds.

Second, the general public was able to suggest ideas through public workshops for the allocation of these funds. They were given the opportunity to comment on proposals, and the process was used to develop and evaluate these proposals. The public generated over 500 ideas for proposals.

Third, the evaluation was an iterative process in which the evaluators and the proposers were in close contact with one another in the development and final evaluation of the proposals. This was not an evaluation in the classical sense in which a proposal (or program or project) is submitted and the evaluation is conducted on the final product. In the PVEA evaluation, proposals changed as a result of initial evaluations, and the evaluations changed as the proposals evolved. We believe this iterative process resulted in better proposals and evaluations with minimal loss in objectivity.

Finally, we included in the evaluation criteria certain unusual items (feedback and monitoring provisions, low-income impacts, and programmatic/technological innovations) that we believe are important in proposals. We introduced these items to stimulate agencies to consider them in the development of their proposals for this evaluation and in future program development. We also wrote reports on innovative projects in other states and on energy use and low-income households to emphasize the importance of these criteria.[2,3]

While the evaluation process has been completed, the impact of the Evaluation Report continues. Major new PVEA funds available to California will be allocated by the Governor and the State Legislature through the state's budget process. The regular budget process will be assisted by the PVEA planning process implemented through the California Energy Commission (CEC) and by the Governor's PVEA Task Force (composed of eight representatives of the state's main agencies). Using the evaluations contained in this report, the Governor's PVEA Task Force has already developed a plan of expenditure for these funds. The detail of those decisions was incorporated into a series of budget change letters submitted to the Legislature on March 1, 1985.

California state agencies have also used this report in funding several of their projects with existing PVEA funds and in exploring potential programs and projects suggested in the report. Other states are also examining the report to determine how they should determine their distribution of oil overcharge funds.

In conclusion, the evaluation process appears to be having a positive impact on how state agencies spend oil overcharge funds to promote the use of energy conservation and renewable sources of energy.

PLANNED ACTIVITIES FOR FY 1986

None. The project has been completed.

ACKNOWLEDGEMENTS

We would like to thank Paul Gertner, Kent Smith, and Don Wallace of the California Energy Commission for their assistance in the evaluation process. We are especially grateful for the work conducted by the LBL Evaluation Team. Finally, we express our gratitude to Mike Rothkopf for his editorial comments and to the support staff of the Applied Science Division for their help in preparing the Evaluation Report.

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Policy Analysis of Natural Resource Sale Mechanisms*

M. Rothkopf, D. Wood, and C. Bart McGuire

Each year, the federal and state governments transfer natural resources worth billions of dollars to the private sector for development. These resources include oil, gas, coal, timber, and minerals such as uranium. Many transfer mechanisms are used, including claim staking, lotteries, and many different kinds of auctions. Auction mechanisms used include oral and sealed bidding for lump sums, unit prices, royalty percentages, or profit shares. In addition, there are many different rules and practices that affect the conduct and results of natural resource auctions. Among these rules are restrictions on joint bidding by potential competitors, choice of bid variables, restrictions (such as minimums) on acceptable bids, and criteria for rejecting all bids. The state or federal government in choosing its rules have several objectives; these may include increasing government revenue, the economic efficiency of the transfer and resource development process, fairness, and avoiding the appearance of unfairness.

The general purpose of the research reported here is the analysis of policy issues related to the design of resource transfer mechanisms and the development of tools to support such analyses. One particular objective has been the development of a simulation model to analyze a particular form of auction used by the U.S. Forest Service to sell logging rights in national forests of the western United States. Another particular objective has been an analysis of two issues related to federal coal leasing: the use of negotiations instead of auctions for "captive" coal tracts and the impact of changed rail rates on Bureau of Land Management (BLM) leasing revenue.

ACCOMPLISHMENTS DURING FY 1985

Unit-Price Auction Simulation

Currently, the Forest Service logging rights auction is a progressive oral auction in which bids are vectors of unit prices for each marketable species of tree on a tract. The total amount of a bid is the inner product of the bid vector with a vector of Forest Service estimates of the quantities of each marketable species. The whole tract is awarded to the high bidder figures on this basis, but the payment by the winner is made at the time the trees are cut and is based upon the actual, not estimated, quantity harvested. Bidders have discovered that they can profit by "unbalancing" or "skewing" their bids to take advantage of perceived Forest Service estimating errors—especially an overestimate of a minor species. The Forest Service has been criticized for sales in which this occurred,[1] and is considering rule changes to limit skewed bidding.[2,3] The bidding literature contains insightful analysis of how bidders can best bid in such unit-price auctions,[4,5] but only a little analysis of how bid takers can best manage them.[6]

Our unit-price auction simulator models the quantity and value estimating processes of the seller and of each bidder, and each bidder's strategy choice. It performs a Monte Carlo simulation of the auction to evaluate a variety of measures of auction performance, including the probability that at least one acceptable bid is received, the expected revenue received by the seller, and the probability that each bidder (including each less efficient one) wins. These simulations can be repreated for various sets of auction rules to estimate the effects of rule changes.

Several kinds of bidding strategies can be treated by the model. The model will handle bidders who skew their bids in the manner suggested by Stark[4] and those who do not skew their bids. The model characterizes a bidder's strategy in terms of two factors: the maximum fraction of his or her tool value estimate the bidder is willing to bid (if competing bids make this necessary) and, for skewing bidders, the additional fraction of the estimated additional profit from skewing that the bidder would "give back" in the form of further bid increases (again, if competing bids make this necessary). Bidders' strategies characterized in terms of these two fractions may either be prespecified or be classified as "optimal." For bidders with "optimal" strategies, the model adjusts the two fractions that compose the strategy so that (within tolerances) no further adjustments could increase that bidder's expected profit. If there are two or more bidders with "optimal" strategies, then the strategies of each must be adjusted to find (to within tolerances) a Nash equilibrium set of strategies in which no optimizing bidder can unilaterally improve his or her own expected profit.

Stark's original work on skewed bidding[4] showed that the optimal pattern in skewing bids is the solution of a linear programming problem and, furthermore, that in certain situations the optimal pattern

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of skewing could be determined without resorting to iterative calculations (such as the simplex method). We have used this result and extended our ability to obtain essentially noniterative solutions to two additional kinds of constraints, including those proposed by the U.S. Forest Service.[2,3]

Finding optimal or equilibrium strategies is computationally difficult because each evaluation of the objective functions of the bidders for a given set of strategies requires a Monte Carlo simulation. Such evaluations involve a substantial computational effort, one that increases as the square of the required precision.

We have used three methods for equilibrium calculations. The first method involves running a set of Monte Carlo simulations in a pattern suggested by experimental design considerations, fitting quadratic surfaces to the results, finding the equilibrium on the quadratic surfaces, and iterating with a new pattern centered around this point. This method is related to an approach discussed by Glad and Goldstein.[7] The second approach is specialized, applying only to situations in which all optimizing bidders are identical for strategic purposes. It looks for symmetric sets of equilibrium strategies by varying one bidder's strategy and using the results to make a damped adjustment of all bidders' strategies. The third method is more general, applying to both symmetric and asymmetric auctions. It determines each bidder's best strategic response for several fixed values of the opponents' strategies, and fits functional forms to these values. We find the equilibrium strategies by locating the intersection of these functions.

Of the three methods, the third is generally superior, and was used to produce most of our results. The first approach is the most direct, but our problem seems to require strong curvature of the fitted surfaces or unreasonably good initial guesses for convergences. The second method (when it can be used) converges quite quickly for reasonably good initial guesses, but provides no direct way to estimate the uncertainty of the equilibrium except by replicating the entire algorithm. This replication, if required, would make it more costly than the third method. Versions of all three methods have been implemented on the CDC 7600 and/or LBL's MIDAS parallel processor computer.

The second and third approaches both require finding a bidder's "best response strategy" to opponents' fixed strategies. We have tried two approaches to this subproblem: an iterative application of simplex search[8] and a fairly straightforward application of classical response surface methodology. Of these, the second method has been more useful.

Use of the simulator has lead us to the following preliminary conclusions:

(1) For some auction conditions, near-optimal strategies for a bidder (given the strategy of his competitors) cover a wide range of "givebacks" of anticipated profits from skewing. Hence, little is lost by assuming that "giveback" is arbitrarily fixed rather than optimized. This significantly eases the calculation burden of finding equilibrium strategies. Fig. 1 illustrates this.

(2) To the extend that equilibrium strategies can be relied upon, it appears that if there are two or more optimizing bidders (who are also skewing bidders and who value the timber equally), then much of the apparent revenue gain by winning bidders who skew will be competed away. Fig. 2 illustrates this.

(3) In these auctions, symmetric equilibrium bidding strategies are more aggressive with few bidders. Unlike sealed-bid, first-price auctions, this is true in comparing two-bidder auctions with three-bidder auctions. In addition, at equilibrium, expected government revenue increases and the expected profit of the winning bidder decreases with the number of symmetric bidders. Fig. 3 illustrates this.

(4) When there is only one skewing bidder, the effect of skewing on government revenue can be severe. Table 1 illustrates this.

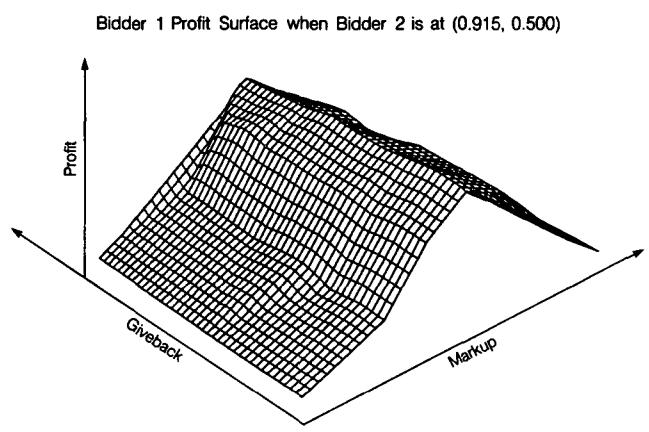

Figure 1. An example of a surface fitted to simulation results that illustrate the common situation in which "giveback" strategy does not significantly affect a bidder's expected profit. (XCG 854-9810)

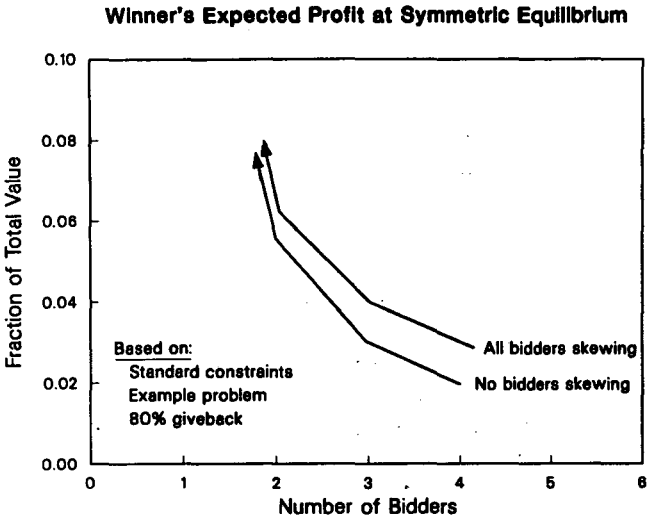

Figure 2. At symmetric equilibrium, much of the apparent extra profits from skewing are competed away. (XCG 854-184)

Analysis of Captive Coal Lease Negotiations

The Commission Fair Market Value Policy for Federal Coal Leasing made many recommendations.[9] One of the difficult but common problems it dealt with is the "captive tract" situation in which a coal tract is of substantial value to only one private party.

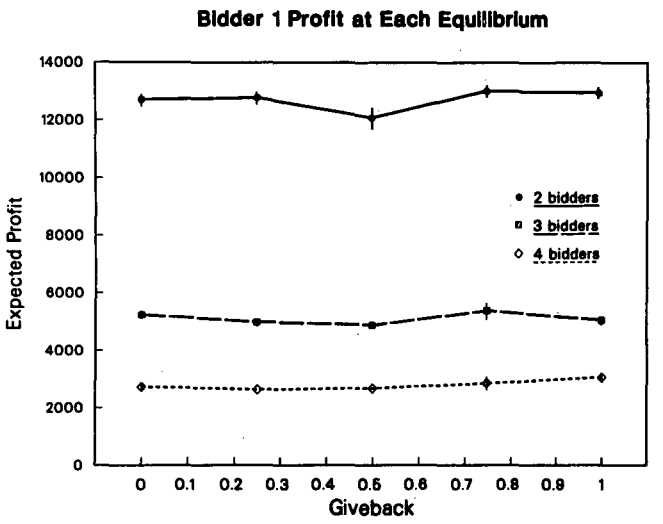

Figure 3. This figure shows the expected profits at equilibrium of bidders in symmetric action. As the number of bidders increase, the expected profit of each bidder falls by a greater factor; hence, profit paid by the government decreases. This figure also shows again the unimportance of the "giveback" part of bidder strategy. (XBL 854-185)

Table 1. One skewing bidder—one non-skewing bidder.

Constraints	Lower Markup[a] at Equilibrium
None	~0.25[b]
"Standard"	~0.625[b]
"Tight"	~0.875

[a]Since this is a second price auction, the lower markup largely determines the price.

[b]Equilibrium unstable—also, values below ~0.65 are extrapolations into a region with <1% of auctions won by lower bidder.

In such a situation, the government is unlikely to obtain more than one competitive bid. Furthermore, the value of the tract is likely to be difficult to estimate. Such situations prompted the Commission to recommend that the government consider negotiations as an alternative to competitive sales.[9] We have analyzed negotiations as an alternative to competitive sales and identified a number of situations in which negotiations of an appropriate kind are advantageous. In this analysis, we have considered various criteria including economic efficiency, government revenue, fairness, the appearance of fairness, and administrative workability.

Our analysis, currently in the form of a draft report,[10] draws upon such parts of bedding theory and bargaining theory as are relevant. It notes the advantages of negotiating exchanged under existing regulations that leave the government with economically logical potential runnable tracts. It also notes the advantages of negotiating shares for the "cooperative leasing" by auction of such tracts. Each of these procedures when usable, will reduce the valuation issues determined by nonmarket mechanisms by converting "captive" tracts into competitive tracts.

For other "captive" tracts, the report finds that there are significant potential advantages to lease negotiations provided that:

1. all negotiations are tentative, subject to "validation" of their one bidder nature in a post-negotiation formal sale procedure (we find that post-negotiation "validation" has clear advantages over pre-negotiation "validation.")
2. the government gains leverage in its negotiations by negotiating on more leases than

it will conclude, using whenever possible one of the "round-robin" negotiation procedures we describe,

3. government employees and not independent agents negotiate for the government, and
4. negotiations are narrowly confined to the amount of the lease bonus.

The report also suggests that the government may wish to consider the use of final-offer arbitration on leases, such as "bypasses," on which both the government and the only interested private party have high interest in an agreement being reached. Fig. 4 shows a potential decision sequence for selecting a mechanism for a coal lease sale.

The report analyzes requiring the use of economic evaluation models in the negotiating process and the use of negotiation fees. While economic evaluation models may well be useful, the report points out some serious problems associated with *requiring* that negotiations conducted be solely in terms of discussing inputs to such a model. The report also raises concerns about the use of negotiation fees. If such fees are used in spite of these concerns, the report notes advantages to the fees being neither refundable nor creditable against a lease bonus.

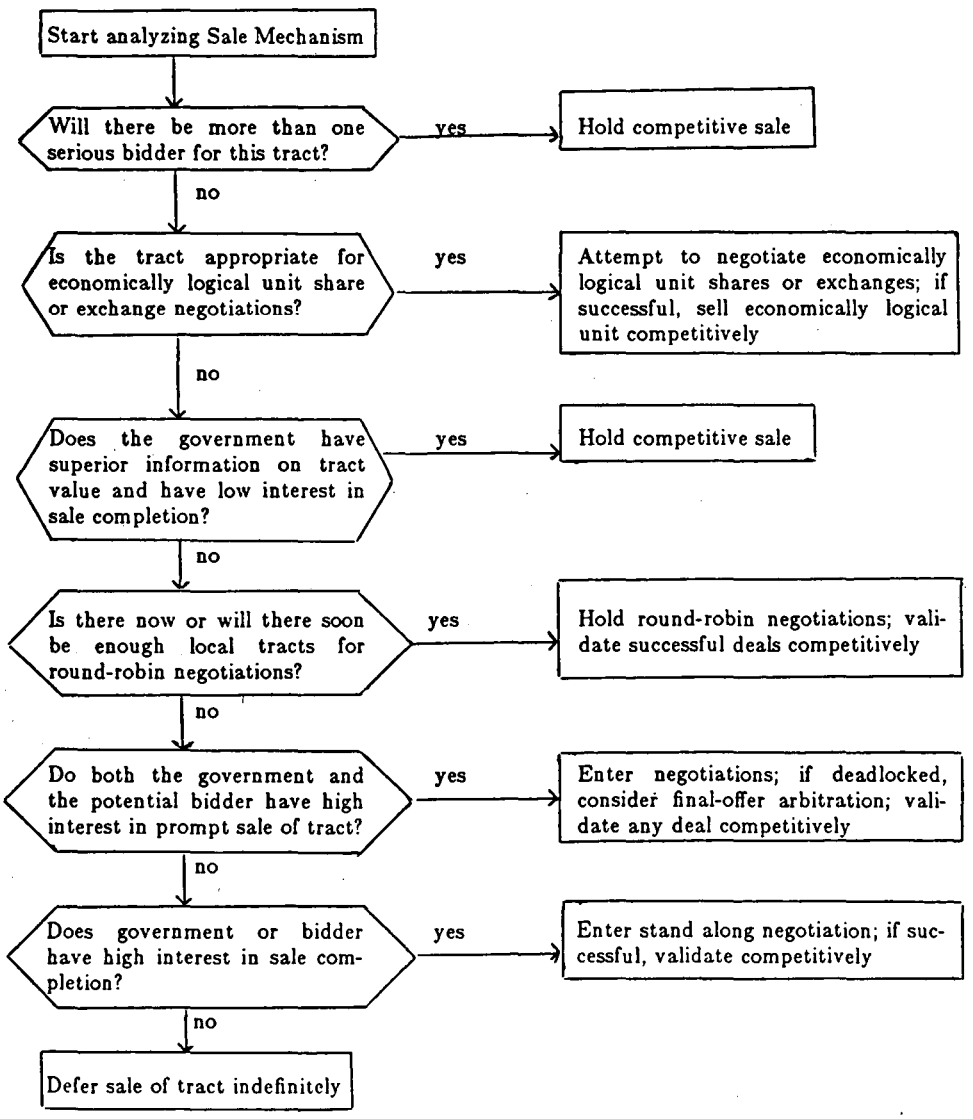

Figure 4. Potential decision sequence for selecting a sale mechanism for a coal tract. (XBL 862-442)

Effect on Government Revenue of Higher Coal Prices

In support of the BLM's responsibility with respect to the management of federal coal, we performed a theoretical economic analysis of the long run effect on federal revenue of an increase in coal prices such as one that would be caused by a reduction in railroad charges for transporting coal. We derived the formulas for two elasticities. The first of these, ϵ_Q, is the elasticity of the quantity of coal produced with respect to the price of "upstream"—i.e., preshipment—coal. The second elasticity, ϵ_R, is the elasticity of the residual value upstream coal with respect to price. These elasticities are given by

$$\epsilon_Q = \epsilon_s\epsilon_d/(\epsilon_d - \epsilon_s)$$

and

$$\epsilon_{Rr} = (\epsilon_s + 1)\epsilon_d/(\epsilon_d - \epsilon_s),$$

where ϵ_s is the price elasticity of coal supply and ϵ_d is price elasticity of coal demand.

The first of these elasticities, where combined with the direct effect of the price increase, gives the total long run effect on government and *ad velorum* royalties. The second, when combined with an analysis of the ability of the government to capture residual value in lease sale bonuses, gives the effect on government revenue from such bonuses. We reviewed the various bidding models of bonus capture and concluded that for the conditions faced by the Bureau of Land Management a reasonable estimate of the percentage of residual value captured by the government as a function of the number of serious bidders was 15%, 60% and 75% for 1, 2 and 3 bidder sales, respectively. We have documented our analysis in a memorandum.[11]

PLANNED ACTIVITIES FOR FY 1985

We plan to complete a paper on our Forest Service auction simulation, analyze future issues related to the sale of Federal coal tracts, and survey the uses of bidding to sell natural resources by the State of California. We also hope to analyze the sale of "options to lease" instead of leases for coal tracts.

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A Natural Gas Policy Model*

T.J. Teisberg,† B.A. Miller,† and M.H. Rothkopf

Natural gas supply in the U.S. has recently undergone major changes in regulatory environment, and further changes are being contemplated. Furthermore, there is a contract structure between gas producers, gas pipelines, and gas customers that, in part, predates current regulations and poses potential problems for further regulatory changes. To help analyze the effects of various regulatory policies, we have constructed an initial version of a "conceptual" linear programming model. The model is concerned with the "short run" behavior (i.e., behavior under given contracts) of individual pipelines. It is designed to help answer questions such as

(1) Do pipelines have incentives to shut-in low cost gas and produce high cost gas when gas is in surplus and there are take-or-pay obligations on the high cost gas?
(2) How are pipelines' decisions about shutting-in production affected by the existence of pipeline affiliated gas supply?
(3) Why do pipelines resist proposals for contract carriage, and does the level of resistance depend upon the source and destination of the transported gas?
(4) How do alternative pipeline rate designs affect efficiency in natural gas markets?
(5) What is the effect of old gas price decontrol, with and without renegotiation of high cost gas contracts

Such a model can take as exogenous burner tip gas demand and wellhead gas supply conditions. However, in order to be useful it must incorporate a number of potentially inconvenient aspects of the situations faced by pipelines including:

(1) A pipeline transportation network with capacity constraints on links in the network.
(2) Gas storage at nodes on the pipeline network.
(3) Gas supply available from contracts with differing prices and differing take-or-pay requirements.
(4) Explicit representation of gas supply from pipeline affiliated sources.
(5) Explicit representation of non-system (transportation) gas.
(6) Gas demand markets with differing price elasticities of demand.
(7) Seasonality of demand.
(8) Capacity to vary the pipeline rate structure.

ACCOMPLISHMENTS DURING FY 1985

This project was initiated during FY 1985. We identified the problem defined above and the need for a model with the features listed above. We then reviewed the following models to determine their suitability for answering the policy questions in which DOE was interested:

(1) Energy Information Administration, Gas Analysis Modeling System (GAMS), DOE/EIA-0450/1, August 1984.
(2) ICF, Inc., Updated Natural Gas Forecasts using Two-Market Model, September 1982.
(3) Decision Focus, Inc., A Regional Model of the United States Natural Gas Production, Transmission, Distribution and Consumption System, September 1984.
(4) Beltramo, M.A., Manne, A.S., and Weyant, J.P., A North American Gas Trade Model: GTM, September 1984.

The first model, GAMS, is a very large scale computer model. It consists of 4000 lines of FORTRAN code, and it requires 30 minutes of CPU time on a mainframe computer to execute. GAMS is so large because it simulates the gas market from the exploration for new gas reserves to the consumption choices of gas consumers, and the impact of macroeconomic variables on those choices. Exploration decisions, for example, are modeled as the solution of a linear program, and pipeline gas acquisition decisions are modeled as the solution of a dynamic program.

Because GAMS is so large and detailed, it was judged to be unsuitable as a conceptual model for understanding pipeline behavior. Also, for all of its detail, GAMS does not include some of the specific features mentioned above. These features are gas storage activities, an explicit representation of pipeline affiliated gas supply, and an explicit distinction between system gas and non-system gas (i.e., transportation gas).

The second model is the ICF Two-Market model. In scope, it is similar to GAMS, since it simulates the gas market from the exploration for

*This work was supported by the Policy, Planning and Analysis Office of the U.S. Department of Energy under Contract No. DE-AC03-76SF00098.

†Applied Decision Analysis, Inc.

new gas to the consumption choices of gas consumers. Although the ICF model is considerably smaller than GAMS, it was still judged unsuitable as a conceptual model of pipeline behavior because of its large scope and because it does not incorporate certain features mentioned above. Features not incorporated include seasonality of demand, gas storage, a detailed pipeline transportation network, contract take-or-pay provisions, pipeline affiliated gas supply, and an explicit distinction between system and non-system gas.

The third model, created by DFI, is essentially a network representation of the US natural gas market, where the network structure is derived from a map of major natural gas pipelines. The model is solved by equilibrating supply and demand at nodes of the network. Transportation between nodes of the network adds a simple markup to the cost of gas at the originating node.

The national scope of the DFI model is neither necessary nor desirable in a conceptual model intended to develop understanding of pipeline behavior. Furthermore, a number of features listed above are not available in the DFI model. These include seasonality of natural gas demand, storage of gas, pipeline affiliated gas supply, and supply contracts which set take-or-pay quantities and prices for each supply node, explicit representation of non-system gas transportation, and alternative pipeline rate structures.

The fourth model is the Gas Trade Model (GTM). Like the DFI model, GTM is a network model of the US natural gas market, with particular emphasis on the role of Canadian and Mexican natural gas imports in the US market. Also, like the DFI model, GTM does not offer a number of important features. These include seasonality of natural gas demand, storage of gas, pipeline affiliated gas supply, and supply contracts which set take-or-pay quantities and prices for each supply node, non-system gas transportation, and alternative pipeline rate structures.

After this review, we designed a new model to answer the policy questions of DOE's Office of Economic Analysis and to incorporate the features listed above, which DOE wished to be included in the model. This model is a linear programming model, which we will refer to as the One Pipeline LP.

The One Pipeline LP explicitly focuses on pipeline decision making within a transportation network, and over the course of an annual cycle of demand. Specifically, the pipeline decides (1) how much system gas to take from supply regions/categories for delivery to demand regions/classes, (2) how much non-system gas to transport, (3) how much gas to store/withdraw at any location. and (4) how much gas to pre-pay (as required by take-or-pay provisions) at each supply region/category. The model is formulated as a pipeline profit maximization linear programming problem. All of the features listed above are included in the One Pipeline LP model.

The One-Pipeline LP is capable of simulating a range of situations including the following:

1. "Current situation," with surplus gas, prepayment of low cost gas, and production of high cost gas.
2. Possible tendency for pipelines to shut-in non-affiliated gas, while producing affiliated gas.
3. Varying degrees of pipeline willingness to transport gas on a contract basis, depending upon the profit from such carriage, and the extent to which such carriage relieves take-or-pay, or serves demand otherwise served by pipeline system supply.
4. Effect of alternative pipeline rate designs.
5. Effect of old gas price decontrol, with or without contract renegotiation.

The details of the initial prototype One Pipeline LP model and illustrative results obtained from it are contained in a report written by Teisberg.[1] This prototype model has been applied so far using hypothetical data only. However, there still appear to be a number of insights that can be derived from these results. Perhaps the three most important insights are the following:

First, the incentive for pipelines to product affiliated supply rather than non-affiliated supply appears to be very strong; in all of the cases modeled so far affiliated supply is produced to the capacity limit. In reality, it may not be politically possible for a pipeline to arbitrarily produce its own gas in preference to others' gas. However, the results here suggest that pipelines will favor production of their own gas to the maximum extent possible.

The second important insight from the model concerns the relationship between the pipeline's gas production choices (and hence its weighted average cost of gas) and (1) the elasticity of demand, (2) the extent to which fixed cost is recovered through unit charges, and (3) the cost of pre-paying gas. Specifically, a pipeline will tend to produce the lower cost gas and shut-in the higher cost gas if (1) its demand is more elastic, (2) its fixed costs are relatively heavily loaded into unit prices, and (3) the pipeline does not perceive a high cost to pre-paying gas. Since two of these last three factors are directly influ-

enced by regulatory policy, it may be advisable for regulators to consider the possible implications of regulation on a pipeline's choice of which gas to produce and which to shut-in.

The third important insight from the model concerns decontrol. The illustrative results reported above indicate that if decontrol means an increase in the cost of oil gas, then decontrol may reduce welfare. This is possible because decontrol without price reduction raises average gas costs above market clearing prices, thereby reducing throughput and consumer welfare. However, there are at least two important qualifications of this conclusions. First, it is possible that decontrol of old gas would put sufficient pressure on pipelines that they would seek and obtain substantial price concessions on high cost gas supplies. Second, the results here take no account of possible welfare gains from increased recovery from price decontrolled old gas fields.

PLANNED ACTIVITIES FOR FY 1986

During FY 1986 we expect to expand the model, further document it, and apply it to a specific pipeline. An initial extension will be improving the ability of the model to handle the effects of purchased gas cost adjustment regulations.

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INTERNATIONAL ENERGY STUDIES

Residential Energy Use in Industrialized Countries*

Lee Schipper, Andrea Ketoff, Stephen Meyers, Peter Goering, and Dianne Hawk

For several years, the International Energy Studies Group at LBL has been following residential energy use and its underlying structure in the major Organization for Economic Corporation and Development (OECD) countries. Recently this work was expanded to include the services sector. The goals of the work are to 1) establish a data base on energy use in homes and buildings in OECD countries; 2) analyze the components of changes in energy use since 1973, particularly the permanence of these changes; 3) extend this analysis through econometric work; 4) analyze the relationship between government conservation programs, and actual savings in the residential sector; and 5) evaluate techniques or policies from overseas that may be applied in the United States.

Since official data covering these sectors are almost non-existent, the group has gathered information on every aspect of energy use from numerous private and government sources. Thus, we collected and analyzed data on the building stocks, heating fuel choices, unit consumption, electric and gas appliances, prices, incomes, conservation programs, and other components of residential energy use. These results are summarized in recent reviews,[1,2] whereas our groundwork is published in a variety of other papers.[3–8]

ACCOMPLISHMENTS DURING FY 1985

Our work led us to examine total energy consumption by fuel and end-use for the period 1960–1983, with an emphasis on the period after the 1973 oil price shock. In most countries (Canada, U.S., W. Germany, France, Sweden, Denmark, UK), energy use declined through 1975 due to reductions in space heating intensities. Primary energy use continued to grow because of increased electric appliance ownership and, in the case of Canada, Norway, and Sweden, because of the growing popularity of electric heating. The second oil shock (1979) unleashed a torrent of energy conservation activity. These conservation efforts continued to influence residential energy use through 1983. Oil use per home fell dramatically in every country as a result of reductions in space heating intensity and increased use of wood or electricity as a secondary fuel. Electricity use per home for appliances virtually ceased

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to grow as newer, more efficient appliances entered the stock. Gas use per home stopped growing in countries where saturation growth continued to be strong, e.g., France, Germany, and Holland, and declined markedly in the U.S. and Canada.

The continued increase in electricity use for space heating—most notable in Norway and Sweden but also important in France, Canada, and the U.S.—accounted for much of the increase in primary energy use per dwelling, although, electric heating in each country became more efficient as new homes with tight shells entered the stock.

The Decline in Oil Use

The decline in residential energy consumption was driven primarily by curtailed oil use. We examined home oil consumption in great detail.[9,10] For six major OECD countries (Canada, Denmark, France, Norway, Sweden, and the U.S.), home oil use decreased between 31% and 55% during the period 1972/3–1983. In W. Germany, oil consumption did not decline this dramatically: W. Germany consumed 13% less oil in 1983 than it did in 1972. Together these countries achieved an oil savings of about 1.2 million barrels per day [59 million tons of oil equivalent (MToe) per year]. One-third of these savings were induced by reductions in the number of homes heated with oil; the remainder resulted from reductions in oil use per oil heated home. During this period, however, the size of these homes and the penetration of central heating throughout the housing stock increased significantly; hence, these figures underestimate the real conservation efforts made to date. For Canada, France, Norway, and the U.S., we estimate that between 50% and 65% of the savings in oil use per household arose from technical measures and should be permanent; the rest resulted from short term changes in behavior. Denmark, Germany, and Sweden represent the extremes in this analysis. Because of the great increase in the number of oil-heated homes in Germany, the permanent reduction in oil use from lower intensities was outweighted by growth in consumption due to changes in structure. In Denmark, only 25% of the oil savings should be considered permanent; in contrast, we estimate that over three-quarters of the savings in Sweden arose from permanent measures. If heating oil supplies were interrupted today, or if prices suddenly shot up, the Swedes would be in the best position to reduce consumption. Most users in other countries would be hard pressed to make great cuts in the very short term.

Oil is on its way out of the residential market. The share of oil in final residential energy use fell from between 53% and 71% (Canada, Denmark, France, Germany, Sweden) in 1972/3 to as little as 24% in Canada, 36% in Sweden and 40% in France by 1983. Germany and Denmark have remained somewhat more dependent on oil: 47% of residential energy use in Germany is based on oil and 52% in Denmark. Shares in the U.S. and Norway have always been lower than in the above-mentioned countries—13% and 18%, respectively.

Just as increases in the price of heating oil influenced oil use in 1973 and in 1979, it is likely that recent price drops will affect oil demand. Although data are preliminary, it appears that, as a result, conservation incentives have diminished. After 1982, oil use per oil heated home did not decline as much as in previous years and may actually have increased slightly in a few countries. While there is some indication that oil users may be losing interest in reducing their oil bills, momentum for conversions to other fuels is strong in every country.

The Oil Substitutes

By 1983 the near term effects of the 1979/80 price shock appeared to have worn off, and consumers appear to have gained a permanent awareness of the economic benefits of efficient energy use. Gas, electricity, and district heating continue to fight for the heating market abandoned by oil. This year we have initiated two studies concerning fuel substitution. One focuses on the substitution of electricity for oil and the other traces the transition to gas from various other fuels.

We have analyzed the emergence of electricity as a primary energy source in the sector. The past 25 years fall into four periods punctuated by changes in world oil prices that affect all aspects of energy supply and demand: the period prior to the 1973 Oil Crisis, the proceeding years up to the second round of oil price increases (1973–1979), the following period of increasing oil prices (1979–1982), and the last three years, which have been marked by more stable oil prices and diminishing concerns over energy in many countries. Growth in electricity use can be attributed to different factors in each of these four periods. Prior to 1973, electricity consumption increased due to 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 rather than oil-fired equipment. In addition some homeowners converted from oil-fired to electric space and water heating. After the second oil price shock in 1979, and throughout the following years of increasing oil prices, the growth in electricity consumption was due

primarily to conversions. Finally, in recent years growth in electricity consumption has slowed, and in some cases consumption has actually declined. This trend can be explained by three factors: increased appliance efficiency, greatly improved thermal integrity of building shells, and increased electricity prices.

Many other aspects of electricity use need to be investigated and compared on an international basis. These areas include, for example, appliance saturation in low vs. high income countries; distribution of consumption over various end-uses; consumption per capita, per dwelling, and per unit; policy initiatives and their effects; and the behavior of households with either primary or secondary electric heating equipment (what are the most common fuel combinations in households with both systems; how is the secondary system used?).

In order to undertake a systematic treatment of information in the energy market and to make forecasts of future gas consumption, we are developing a formal model of gas demand in the residential sector (see description in following article). The rapid expansion of gas networks in the European countries has motivated conversion from heating oil in both apartments and homes. Analysis based on historical data indicates that intensity of gas use for space heating appears to be falling slowly but steadily in Holland, the United Kingdom, and the U.S.—the three countries with the greatest dependence on gas.

Conservation Policies

What role have policies played in all of these changes? Very few policies governing energy use in existing homes have been enacted. Building codes have been implemented for new buildings in most OECD countries. Usually these codes do not go beyond the practices already adopted by builders for economic reasons. Only in the U.S. do changes in building practices lag behind what appears to be economical.

In Sweden,[11] a complex system of building codes linked to financial support for builders and buyers (in place since the early 1960s) clearly stimulated the building industry to produce far more efficient homes than anywhere else. The extra costs incurred were automatically financed through normal home-financing channels. This led to practices that were on average better than what was required by codes. The Swedish building code required R values of 19 for walls and 25 for roofs. In 1983, the average R value in Sweden was 25 for walls and 40 for roofs. Similarly, through the retrofit grant program in Sweden, administered by a key group that was in place long before 1973, nearly 2/3 of the stock of single-family dwellings and half the apartments have been insulated or subjected to various other conservation techniques. These figures have not been matched in any other country.

In other OECD countries, the impact of policies is not clear. This is because energy savings came about through rapid reductions in energy intensities for heating fuels, principally oil. Denmark, W. Germany, France, and the U.S. are important examples. In Holland, the reduction in gas heating use has been gradual. In this country, the National Insulation Program, which will eventually reach most of the eligible dwellings, is responsible for this decline in consumption.

The impact of government policies is being felt more in the 1980's than in the previous decade. In Denmark and France, programs in the mid-1980s appear to be replacing the "quick and dirty" savings won in 1979/1981 with more permanent savings through the provision of better building shells and equipment. In our judgement, these programs are substantially increasing the rate of investment in retrofit measures by enabling households to improve comfort at a low cost. Thus we find that while conservation programs and policies had only a minor effect in the 1970s, they are bearing fruit in the 1980s in most European countries. In all these countries, new homes heated by gas or electricity and new electric appliances are considerably more efficient than the older ones. This was accomplished without strict codes/standards in place. The U.S. appears to have achieved less improvement in appliance efficiency than other countries.

Promising Foreign Technologies

Our work has uncovered several new technologies that may benefit the United States. One of the most impressive is the exhaust-air heat pump for domestic hot water heating. The device currently outfits half of the new single-family dwellings stock in Sweden.[11] This small device uses the stream of 20°C air from the house ventilation system (active ventilation is necessary in very tight houses) to provide roughly half of the energy required for domestic hot water. If the home uses a hydronic space heating system, surplus heat from the heat pump can also heat the home. Other promising technologies from Europe include bivalent (two-fueled) heat pumps—promoted in France, condensing gas furnaces, and multi-fuel boilers that use oil (or gas), wood, or electricity, depending on which is most advantageous to use. Finally, electric appliances have become more efficient in every country, judging from catalogues

from the major manufacturers (Philips, Electrolux, Mitsubushi). Equally important, the market has absorbed these devices, perhaps to a greater extent in Denmark, Germany, and Japan than in the U.S. Indeed, many observers await an invasion of very efficient appliances from Japan. High electricity prices and government guidelines have stimulated technical developments in Japan.

Perhaps the most dramatic technology, however, is the wooden house itself.[11] Factory crafted houses from Sweden (with some from Norway and Denmark as well) have the best thermal performance of any production houses in the world, at minimal extra cost. In our study[11] we found that houses built in Sweden in the late 1970s and early 1980s generally performed as expected. We also found that with the exchange rates of 1984/5, these houses could be profitably exported to the U.S. More importantly, the Swedish factory crafting techniques could make low-cost thermal comfort available in new U.S. homes. As of May, 1985, the construction of nearly 300 Swedish homes was planned in the U.S. (mostly in the East), and an advanced home from Denmark had recently been assembled at the Brookhaven National Laboratory.

PLANNED ACTIVITIES FOR FY 1986

During 1986, we will be following these developments carefully to see whether falling oil prices will lead to less interest in efficient home energy use, or whether the events of the 1970s and the knowledge gained from experimenting with new ways of saving energy, coupled with today's incentive programs for energy savings, will lead to even more reductions in the cost of basic comforts and energy services. We will also analyze trends in natural gas and electricity use and extend this analysis through econometric work. Based on the results of these studies, we will develop possible scenarios for future energy use in OECD countries.

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Energy Use in the Service Sector: An International Perspective*

Lee Schipper, Steven Meyers, and Andrea N. Ketoff

The service sector has become more important in recent years because it has shown the strongest growth, particularly in the use of electricity. In FY 1984, the International Energy Studies Group of the Energy Analysis Program began an international compilation and analysis of data concerning energy use in the service sector. Our first publication, containing data and analysis on the structural setting for service sector energy consumption and on trends in service sector energy consumption between 1970 and 1982 for eight industrial countries, appeared in FY 1985.[1]

ACCOMPLISHMENTS DURING FY 1985

Commercial sector *delivered* energy consumption has either declined or grown slowly since 1971/72 in the eight countries for which we have reliable time-series data —Canada, Denmark, France, Germany, Norway, Sweden, the UK, and the U.S. (see Table 1). Denmark has seen the largest decline (8%), while Sweden has seen the biggest (but still modest) increase (7%). Delivered energy consumption *per capita* has fallen or stayed the same in all eight countries. All indications are that commercial sector energy use grew faster than the residential sector before 1971/72; after this time both sectors grew more slowly, but commercial still outpaced residential, or at least contracted more slowly.

Part of the decline in delivered energy consumption may be attributable to structural changes that lead to the use of fuels that are more energy-efficient in terms of delivered energy. Here we refer to district heat and electricity, which, unlike oil and gas, do not have combustion losses when used at the building site. Counting primary energy shows all of the energy resources that go into district heat and electricity production for the commercial sector. Since electricity production in particular has high energy losses, increasing use of electricity in the commercial sector has led to growth in primary energy consumption. This growth ranged from 1.3% per year in Denmark and 2.4% per year in Sweden to 4.5% per year in electricity-intensive Norway.

The result of differing growth rates has been considerable shift in the shares of the fuels used in the commercial sector. Oil accounted for between 55% (Denmark) and 72% (France) of total delivered energy consumption in the early 1970s. By 1982, the oil share had fallen to between 37% (Denmark) and 47% (France). In Canada and the U.S., where the oil shares in the early 1970s were 33% and 25%, respectively, substantial drops in the oil share occurred as well.

The electricity share of total delivered energy consumption has grown to over 25% in all of the countries: from 16% to 33% in Denmark, from 16% to 29% in France, from 14% to 26% in Germany,

Table 1. Average annual growth rates in service sector energy consumption (%).[a]

	CANADA 1973–81	DENMARK 1972–82	FRANCE 1974–82	GERMANY 1971–83	NORWAY 1972–82	SWEDEN 1972–82	UK 1970–80	USA 1971–82
Delivered Energy								
Total	0.6	−0.9	−0.9	0.0	1.8	0.7	0.3	0.4
Per capita	−0.7	−1.1	−1.3	0.0	1.4	−0.4	0.2	−0.6
Primary Energy								
Total	0.9	1.3	1.4	1.5	4.5	2.4	1.2	1.8
Per capita	−0.4	1.0	0.9	1.5	4.1	2.2	1.1	0.8

[a]First and last years had roughly similar climate.

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from 25 to 38% in Sweden, from 23% to 35% in the U.S., and from 29% to 34% in Canada. Gas consumption has taken on a major share of total delivered energy consumption in France (22% in 1982), Germany (21% in 1982), and the UK (31% in 1980) and has risen to nearly half of total consumption in Canada and stayed at that level in the U.S.

On a per capita basis, commercial sector energy consumption (Table 2) is some 50–100% higher in the U.S. and Canada than in the European countries, which are roughly in the same range, once the colder Swedish climate is taken into account. This finding does not account for differences in the amount of commercial sector floor area per capita. The accuracy and comparability of floor area estimates among countries is difficult to assess. Using the estimates available to us, we found that the greater level of floor area per capita in the U.S. explains some of the difference in per capita energy use. Energy use per square meter of floor area remains considerably higher in the U.S., however. This may in part be attributable to the nearly universal use of air conditioning in the U.S.

Two important indicators for the service sector are energy and electricity consumption per employee (Table 3). We found that delivered energy consumption per employee was lower in 1982 than in 1970 in each of the eight countries. This was due in part to growing penetration of electricity in the heating market. Electricity consumption per employee increased in every country between 1970 and 1982. The increase was particularly great in Denmark, France, and Germany. The increase in electricity intensity slowed in most cases after 1978.

International Workshop

In FY 1985, an international workshop on energy use in the service sector sponsored by the Electric Power Research Institute and co-organized by the International Energy Studies group brought together participants from 10 countries. The topics discussed during the course of the meeting included overviews of consumption trends, data collection and analysis, models and forecasting, and new technologies in buildings. A proceedings is in preparation.

PLANNED ACTIVITIES FOR FY 1986

We will update our data base and further analyze service sector energy use. We will examine the sector in more detail, looking at energy use and structure in subsectors. We will present equipment/fuel choices in new buildings where data permit.

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Table 2. Service sector buildings energy consumption.[a]

	CANADA 1982	DENMARK 1982	FRANCE 1983	GERMANY 1982	NORWAY 1982	SWEDEN 1982	UK 1980	USA 1979
DELIVERED ENERGY								
Total (PJ)	743	69	547	765	64	150	706	5540
Per capita (GJ)	30	14	10	12	16	18	13	25
per sq m (MJ)	1895[b]	870	793	765	1290	1120	—	1325
Primary Energy								
Total (PJ)	1197	120	893	1155	144	270	1209	9620
Per capita (GJ)	48	23	16	19	35	32	22	43
Per sq m (MJ)	3024[b]	1500	1295	1120	2870	2015	—	2300
Climate Index	107.8	94.8	99.1	95.8	98.2	100.7	99.8	102.7
DD Normal (18°C)	4581	3122	2450	3116	4069	4010	2917	2600

[a]Probably includes some non-buildings energy consumption in Canada, Denmark, and Germany. Residential consumption has been removed from U.S. data.

[b]1981.

Table 3. Commercial sector energy and electricity intensity (GJ per service sector employee[a]).

	CANADA	DENMARK	FRANCE	GERMANY	NORWAY	SWEDEN	UK	USA
				Delivered Energy				
1970	139	—	—	84	61[b]	65	56[b]	118
1971	137[b]	—	—	85[b]	66[b]	64[b]	52	117[b]
1972	150	57	—	91	61[b]	65	52[b]	116
1973	125	—	58[b]	94	55[b]	66[b]	51[b]	115
1974	122	—	56[b]	87	54[b]	60	48	108
1975	109[b]	49	50[b]	87	53[b]	62	47	103
1976	119	57[b]	51[b]	91[b]	54[b]	68	49	107
1977	117[b]	56	52[b]	87	55[b]	66[b]	51	102[b]
1978	115	54[b]	53[b]	92	53[b]	66	51[b]	100
1979	109[b]	54	52[b]	94	55[b]	65	52	99
1980	103	49	50[b]	84	53[b]	62	49	94[b]
1981	99	47[b]	49[b]	79[b]	54[b]	58	49	90
1982	102	46	48[b]	74	53[b]	55[b]	49	90[b]
				Electricity				
1970	30.2	—	—	11.5	18.7[b]	13.2	10.3[b]	26.4
1971	31.2[b]	—	—	12.1[b]	21.9[b]	14.8[b]	10.5	27.4[b]
1972	35.1	9.4	—	13.3	22.5[b]	16.2	10.7[b]	28.7
1973	36.5	—	9.2[b]	14.0	23.2[b]	17.1[b]	11.2[b]	30.0
1974	36.1	—	9.7[b]	14.4	26.5[b]	16.1	10.1	28.8
1975	34.7[b]	10.5	10.1[b]	15.1	26.3[b]	17.1	10.7	30.0
1976	36.9	12.0[b]	10.8[b]	16.2[b]	26.5[b]	18.7	11.0	30.5
1977	38.8[b]	12.9	11.4[b]	17.0	28.0[b]	18.8[b]	11.6	30.7[b]
1978	33.5	14.5[b]	12.1[b]	17.9	27.6[b]	19.7	12.1[b]	30.6
1979	34.3[b]	15.7	12.5[b]	18.2	29.8[b]	19.8	12.5	30.4
1980	32.8	14.8	12.9[b]	18.1	30.0[b]	20.5	12.4	30.7[b]
1981	31.1	14.7[b]	13.5[b]	18.9[b]	32.4[b]	20.3	12.8	32.2
1982	33.0	15.4	14.0[b]	19.2	34.5[b]	21.3[b]	12.8	32.4[b]

[a]Source for employees: OECD Labour Force Statistics (Services includes major divisions 6–9 and 0 of the ISIC).

[b]Years of weather within 2 index points of heating degree-day normal. (French and Norwegian consumption data were weather-normalized by the source.) Annual fluctuations in cooling degree-days affect Canadian and U.S. electricity data.

Energy Consumption and Structure of the U.S. Residential Sector*

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.[1] In FY 1985, we began to put together a comprehensive overview of both the trends in U.S. residential energy consumption in the 1970–1984 period and the chief structural factors shaping those trends. 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. Under structural setting we include information on households and housing, penetration of various end uses, the efficiency of equipment, and conservation measures undertaken by households.

ACCOMPLISHMENTS DURING FY 1985

We assembled and compared data from a variety of governmental and non-governmental sources during FY 1985. We worked with data tapes from the Residential Energy Consumption Surveys of the Energy Information Administration in order to gather additional detail. We have focused on trends with respect to the structural setting and energy consumption for the residential sector as a whole, for natural gas, for electricity, for oil, and for other fuels. The key findings from our sector overview are described below.

The Structural Setting

The physical setting for U.S. residential energy use has changed substantially since 1970. The number of households in the U.S. grew from around 64.5 million in 1970 to around 85.4 million in 1984. The combined result of additions and losses is that nearly 26% of the 1983 occupied housing stock was built after 1969.

The average number of persons per household fell from 3.06 in 1970 to 2.72 in 1983. (The median number fell from 2.74 to 2.32.) This means that there is lower demand per household for certain purposes (especially water heating and clothes washing/drying). The percentage of 1-person households rose from 18% in 1970 to 22% in 1983, while the percentage of 2-person households rose from 30% to 32%. Along with the increased participation of wives in the labor force, this has probably resulted in more homes being left empty (and at lower indoor winter temperature) today than in the early 1970s.

The average U.S. household is located in a slightly warmer climate today than in 1970. A lower percentage of households lived in single-family houses in 1983 (68.1%) than in 1970 (71.4%). This trend means that a lower percentage of homes have all walls and ceiling exposed to the weather.

The average home today is better insulated and has lower air infiltration than in 1970. This is due to both retrofitting of older homes and addition of more energy-conserving new homes. There has been an increase in the percentage of single-family homes with storm windows (from 45% to 52%) and in the percentage with attic/roof insulation (from 71% to 78%). Slight increase is evident in the percentage of homes with storm doors. There has been considerable retrofit activity on single-family houses and mobile homes, particularly in the 1979–81 period.

The introduction of new housing into the stock has resulted in improvement in the average thermal integrity of U.S. homes.[†] Data from surveys conducted by the National Association of Home Builders (NAHB) provide evidence of considerable increase since 1973 in the average level of ceiling and floor insulation and in the installation of double and triple window glazing in newly-constructed single-family houses. Data for low-rise multi-family housing, which accounts for 60–85% of all new multi-family housing, show little increase in insulation levels but some increase in the use of double and triple glazing since 1976. Measurements of air infiltration rates suggest that recently constructed homes have lower values than older homes.

The three main trends with respect to energy-using equipment that have affected the level of total energy consumption are the increased electrification of space heating, water heating, and cooking; growth in appliance holdings; and improved energy efficiency of new appliances. The penetration of electricity as main space heating fuel rose from 8% in 1970 to 19% in 1983. The penetration of air-conditioners grew substantially from 37% in 1970 to 59% in 1983.

The major appliances in the average U.S. home today are more energy-efficient than in 1970. New

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[†]Homes built after 1969 accounted for 23% of the 1982 stock of single-family houses, 31% of the 1982 stock of multi-family units, and 73% of the 1982 stock of mobile homes, according to RECS.

refrigerators and freezers in 1984 were on average 60–70% more efficient than in 1972. Central air-conditioners were 30% more efficient, while room air conditioners were 25% more efficient. Gas space and water heaters were around 15% more efficient.

Survey data on energy-conserving behavior by U.S. households provide evidence of considerable change in heating practices. The most important change has been a major reduction in winter indoor temperatures. The percentage of households keeping the thermostat at 70°F or higher when someone was at home during the daytime fell from around 85% in 1973 to around 46% in 1981 (the first year RECS collected such information). The percentage of households keeping the thermostat at 70°F or higher during sleeping hours fell from around 51% in 1973 to around 22% in 1981. The RECS data suggest that daytime temperatures crept upward from 1981 to 1982. The percentage of households using small room heaters (electric and kerosene) and wood stoves increased between 1978 and 1982.

Energy Consumption

Primary energy consumption accounted for by the U.S. residential sector, adjusted to approximate normal weather, was 5% higher in 1984 than in 1973 (see Table 1). Delivered energy consumption, adjusted to approximate normal weather, was 9% lower in 1984 than in the peak year of 1973. Useful energy consumption (approximate combustion losses removed) was 5% lower in 1984 than in the peak year of 1973.

The time-series for primary energy shows a drop in 1974 followed by a period of increase up until 1979, and some decline through 1983, 1984 saw a substantial increase due largely to growth in electricity consumption. The time-series for delivered energy shows a larger drop in 1974 followed by several years of very modest increase, gradual decline in 1978–79 followed by a large decline in 1980, and modest decline in 1981–82, followed by a large drop in 1983; 1984 saw the first increase since

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

	Gas	Oil	LPG	Elec.	Coal	Wood	Total Delivered[b]	Elec. Losses	Total Primary[b]	Total Useful[c]
1970	4.98	2.35	0.34	1.59	0.15	0.40	9.61	3.86	13.47	6.81
1971	5.20	2.42	0.35	1.71	0.14	0.38	10.01	4.14	14.15	7.11
1972	5.19	2.41	0.36	1.86	0.11	0.38	10.12	4.47	14.59	7.24
1973	5.22	2.56	0.37	1.99	0.11	0.35	10.43	4.77	15.20	7.48
1974	5.07	2.30	0.38	2.02	0.11	0.37	10.07	4.93	15.00	7.26
1975	5.16	2.26	0.38	2.02	0.09	0.43	10.13	4.88	15.01	7.30
1976	5.12	2.30	0.38	2.12	0.08	0.48	10.24	5.11	15.35	7.41
1977	5.01	2.35	0.38	2.21	0.09	0.54	10.31	5.34	15.65	7.49
1978	4.90	2.18	0.38	2.28	0.09	0.62	10.14	5.58	15.72	7.40
1979	4.96	1.95	0.36	2.38	0.07	0.73	10.09	5.75	15.84	7.41
1980	4.82	1.58	0.33	2.43	0.06	0.86	9.65	5.91	15.56	7.14
1981	4.78	1.43	0.31	2.51	0.07	0.87	9.54	5.98	15.52	7.10
1982	4.75	1.35	0.30	2.52	0.08	0.94	9.47	6.05	15.51	7.06
1983	4.50	1.23	0.35	2.54	0.08	0.93	9.17	6.09	15.26	6.87
1984	4.70	1.25	0.35[d]	2.66	0.08[d]	0.93[d]	9.51	6.38[d]	15.89	7.13

[a]No adjustment has been made to LPG, coal, and wood due to the somewhat uncertain accuracy of the data.

[b]Includes 50% of wood consumption.

[c]Excludes estimated combustion losses: 35% of delivered energy for gas, oil, LPG, and coal, 65% of delivered energy for wood.

[d]Estimate.

1977. The time-series for useful energy shows a trend similar to that of delivered energy, except that the decline is slightly less after 1977. This decline is smaller because part of the decline in delivered energy is attributable to the increased penetration of electricity in the heating market.

Average energy consumption per household, counted as primary energy, adjusted to approximate normal weather, was 15% lower in 1984 than in 1973 (see Table 2). Counted as delivered energy, it was 26% lower in 1984 than in the peak year of 1973. Counted as useful energy, it was 23% lower in 1984 than in the peak year of 1973.

Table 2. U.S. residential energy consumption per household adjusted to approximate normal weather (million Btu).[a]

	Primary Energy	Delivered Energy	Useful Energy
1970	209	149	106
1971	215	152	108
1972	215	149	107
1973	219	150	108
1974	211	142	102
1975	208	140	101
1976	208	138	100
1977	208	137	100
1978	204	131	96
1979	202	129	94
1980	193	119	88
1981	188	116	86
1982	186	113	85
1983[b]	182	109	82
1984	186	111	83

Source: Table 1; Current Population Series (for household numbers).[c]

[a]No adjustment has been made to LPG, wood, and coal.

[b]The CPS number of households for 1983 seems low, given the known additions to the stock. This means that the values given for consumption per household may be slightly overstated.

[c]Published data on households from the CPS for the 1970–79 period reflect the undercounting of the 1970 census (estimated at about 1.1 million households). To correct for this, 1.1 million households have been added to the CPS estimate for each year in this period.

The time-series for primary energy shows a drop in 1974 followed by a period of stability up until 1978, gradual decline in 1978–79 followed by a large drop in 1980, and gradual decline in 1981–82 (see Table 2). 1984 saw the first increase since 1973. The time-series for delivered energy shows a drop in 1974 followed by several years of slight decline, declines in 1978–79 followed by a large decline in 1980, and steady decline in the 1981–83 period. Here too, 1984 saw the first increase since 1973. The time-series for useful energy shows a trend similar to that of delivered energy, except that the decline is slightly less after 1973.

The shares of the fuels in total residential delivered energy consumption have changed as follows (based on Table 1):

	1970	1977	1984
		(percent)	
Gas	52	49	49
Electricity	17	21	28
Oil	24	23	13
LPG	4	4	4
Wood	2	3	5

PLANNED ACTIVITIES FOR FY 1986

We will complete the full report of the project early in FY 1986. We will then produce a condensed version of the full report. We will do additional work on the U.S. residential sector as needed in the context of other International Energy Studies projects.

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Residential Demand for Natural Gas: A Dynamic, Discrete-Continuous Choice Approach*

Oystein Olsen † *and Sarita Bartlett*

We are developing a model as a part of an ongoing project for analyzing gas demand for space heating in the *residential sector* in Western Europe. We are using a *discrete-continuous dynamic choice model.* A reasonable interpretation of this approach is that households' decisions on energy consumption are carried out in two steps. In the first step households have to choose between a limited (discrete) number of fuel systems or technologies. Given this technology choice, a (continuous) decision is made on how intensively the equipment should be utilized. In the short run households can change energy consumption only by varying the intensity in applying the installed equipment, while in a longer time perspective changes in prices and other variables can motivate consumers to convert to another fuel system. Formally, the technology choice involves comparisons of levels of indirect utility attached to the various fuel systems. Consistent with the theory of consumer behavior, we use equations describing gas use per household derived from the indirect utility functions by using *Roy's identity.*

ACCOMPLISHMENTS DURING FY 1985

The technology decision in the present model is a *dynamic, discrete choice.* This is an extension of the traditional (static) approach for analyzing behaviour involving limited dependent variables. In this dynamic version the choice probabilities are, at each point of time, dependent on the technology choice previously made. Assuming that the stochastic (unknown) terms influencing individuals' utility are independently distributed over fuel alternatives and develop over time according to an extremal process (assuming explicitly a structure of autocorrelation in the disturbance terms), time paths for "state probabilities" (frequencies for various technologies) and the transition between alternatives can be described as a Markov process. The transition probabilities are functions of the explanatory variables (fuel prices, conversion costs, income level and socio-economic variables) specified in the indirect utility functions and thus include parameters which are to be estimated. The expressions for the transition probabilities reveal that this dynamic structure may be interpreted as a modified Multi-Nomial Logit (MNL) model.

The dynamic version of the discrete/continuous choice model is particularly relevant when analyzing the demand for natural gas. In this market, significant conversions from other fuels have taken place, and a large part of the potential for future increase in gas consumption, especially in Europe, is believed to consist of conversions. It is therefore important that the model allows for transition from one technology to another, as opposed to the static MNL model, which is probably best suited for modeling investment decisions, or choices, that are irreversible.

We are preparing to estimate the dynamic discrete-continuous choice model from data on energy use in various European countries, differentiated by end use and type of fuel, the number of dwellings and the choice of fuel system and other "structural" and economic variables collected in a database by the International Energy Studies Group at Lawrence Berkeley Laboratory. The model thus applies directly information on how energy consumption is related to the dwelling stock, dwelling size etc. This distinguishes the present approach from most other studies of energy demand. In the first stage of the project, we are modeling only the energy use for *space heating* in the residential sector. This is, however, by far the most important end use, absorbing more than 75 percent of total energy consumption by households in the countries included in this study. Furthermore, it is probably close to realistic to simplify the analyzes and assume that the primary fuel choice is the technology decision for space heating and that this is done separately from choice of fuel system for hot water heating and cooking.

A significant characteristic of the present analysis is that we do not model the demand for housing services or dwellings. The dwelling stock is given exogenously by the model user in order to determine the development of total gas consumption.

PLANNED ACTIVITIES FOR 1986

During the coming year we plan to complete data preparation and model estimation and to report our results.

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†Oystein Olsen of that Bureau is a visiting research fellow at the Lawrence Berkeley Laboratory.

Changes in the Patterns of Oil Use in Latin America

Andre Ghirardi, Peter Goering, and Andrea Ketoff

Despite efforts to develop alternative energy sources, all less developed countries (LDCs) in Latin America still rely heavily on petroleum products. On a worldwide basis, the share of petroleum use is higher in LDCs than in industrialized economies, and LDCs account for most of the net growth in world petroleum demand.

There are wide differences in the behavior of oil demand among LDCs. While the oil importers (or non-exporters) managed some degree of reduction in their oil intensities through substitution and conservation, the oil-exporters generally increased their petroleum intensity.

Although for different reasons, oil substitution and energy conservation are equally important to importers and exporters alike. The predicament of the oil importers is that their purchases of foreign energy sources cost much more now than ten years ago and, in most cases, consume most of their foreign exchange earnings, thus hindering their ability to pay their mounting foreign debt. In the exporting countries, oil invariably accounts for most of the government's income and is the most important source of foreign exchange. While the exporters want to sell as much oil as possible to finance development, their production is limited by world demand, as well as by the size of their reserves.

Among the exporters, Mexico and Venezuela find themselves in financial difficulties despite the richess of their oil reserves. The contraction in oil demand caused by the worldwide recession of the early 1980s severely cut down these countries' incomes. Many exporters are compensating by lowering their prices and producing more, adding much uncertainty to the immediate future of the world oil market.

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After four years of nearly complete stagnation, many economies show signs of recovery. For LDCs, this recovery represents renewed opportunity for growth, increased exports, and possible alleviation of their debt burden.

The possibility of renewed economic growth raises new questions about oil demand. Much of the urban and industrial development taking place in LDCs will contribute to increase demand for petroleum products for industrial processes, urban transportation, and household use. In light of the substantial reduction in petroleum demand achieved by many LDCs during the last decade, two of the main questions on the future of the petroleum market in those countries are: What are the components of the reduction in oil use in LDCs, and where is the reduction likely to be reversed? We examine changes in the composition of economic output, energy conservation and fuel substitution to provide elements that will help answer these questions.

This analysis is based on a sectoral disaggregation of energy use. It associates the trends in energy demand with the observed changes in the levels of sectoral activity. We generally limit the scope of our work to the study of commercial fuels, but we do examine the use of wood for cooking in the residential sector and its potential replacement with LPG and other commercial energy forms.

This study analyzes Argentina, Brazil, Mexico and Venezuela. These countries account for more than 75 percent of the energy and oil use in Latin America and also produce more than 84 percent of the region's GDP.

ACCOMPLISHMENTS DURING FY 1985

During FY 1985, we attempted to quantify the "*oil backout*" in Latin America. We investigated its nature within the main economic sectors and the patterns of oil use among different groups of countries. The assessment of the changes in the Latin-American oil market is based on the sectoral analyses summarized below.

Sectoral Behavior of Petroleum Intensity

The present configuration of the structure of energy demand in Latin America shows signs of some of the adjustments described above and of the severe economic recession, which, despite some isolated improvements in performance, has not been totally overcome.

Between 1981 and 1983, the aggregate petroleum use in the region declined noticeably. Although that

coincides with a recessionary period, the reduction in petroleum use went beyond the effects of low economic activity. There was widespread substitution away from petroleum-based fuels, resulting in a reduction of petroleum intensity, some of which is likely to prevail, even in a healthy economy.

In order to assess the extent of this *oil backout* in the region, we calculated, for each country, how much petroleum would have been used in 1983 if the economies had been operating with the same petroleum intensity they had in 1978. We define *savings* as the difference between what would have been necessary and what was actually consumed.

The results show savings of 20 million TOE, which, while impressive, were unevenly distributed. Brazil and Argentina did in fact achieve overall reduction in the oil intensity of their economy. Venezuela's oil intensity increased, despite some effective substitution of natural gas for fuel oil in industry. The petroleum intensity in Mexico remained virtually unchanged. That is, while the non-exporting countries combined to save approximately 19 million TOE with respect to 1978 levels, the levels of savings in the exporting countries were marginal or nil.

Seventy-eight percent of the reduction in oil use was achieved in Brazil, primarily in transportation and industry. In transportation, Brazil curbed gasoline demand through use of alcohol fuels and, until recently, mandated conservation. In industry there was substitution for fuel oil, mostly with electricity and coal.

The savings achieved in Argentina were nearly evenly split between industry and power generation. The predominant trend in industry was the substitution of natural gas for fuel oil. In power generation both natural gas and hydroelectricity increased their share relative to petroleum fuels. There was virtually no reduction of oil intensity in the transportation sector in Argentina.

Industry

The process of industrialization in Latin America took place at high growth rates during the 1970s, until it was halted by the oil price increase of 1979. Nevertheless, before the recession of the late 1970s and early 1980s, a number of the regional developing economies brought many industrial activities up to the level of international competition. This process is mostly noticeable in the basic and more energy-intensive industries: iron and steel, aluminum, chemicals, cement, and paper.

Production of these items is being transferred to those developing countries that have adopted modern technologies and have the competitive advantage of lower labor costs (than the industrialized economies) and proximity to the raw materials. In most countries included in this study, the relative share of basic industries with respect to total GDP shows a pronounced increase during the 1970s.

The four Latin-American countries analyzed here produced a net petroleum savings of 10.3 million TOE in 1983, with respect to 1978 levels.† Those savings correspond to 37 percent of the combined industrial use of petroleum in those four countries in 1978.

Most of the savings were achieved in Brazil, which is the largest oil importer among LDCs. Smaller savings were achieved by Mexico and Argentina, while Venezuela increased its industrial oil intensity.

The nature of the changes in the patterns of oil use are closely related to the availability of resources in each country. In Argentina and Mexico, the reduction in use of petroleum products in industry is mostly caused by increased use of natural gas. Brazil, besides needing to import most of its petroleum, did not have large natural gas reserves (that has changed now) and managed to reduce oil use mostly through mandated conservation (by limiting the amount of fuel oil made available to each industry) and by subsidizing the use of domestic energy sources such as coal, charcoal, and, most of all, hydroelectricity. Despite a slight increase in the oil intensity of its industry since 1978, Venezuela also promoted large-scale substitution of natural gas for oil in industry.

In all four countries, there were successful efforts to reduce the oil intensity of the cement industry, through substitution with coal (Brazil) or natural gas (Argentina, Venezuela, Mexico). In many cases, there may be complete substitution of petroleum products for cement production. In the countries that are well endowed with natural gas, use of fuel oil in the cement industry could be entirely eliminated.

Large reductions in oil intensity can continue to be realized in the steel industry, as newer and more efficient plants (especially direct reduction) replace old ones. The sector is also increasing its electrification, as the direct-reduction furnaces are coupled with electric-arc steelmaking.

More than any other sector, industrial activity has shown contrasting features in its structure of

†These savings are measured at end-use levels. The primary savings would be higher, and would vary according to each country's efficiency of refining and use.

energy use. On one hand, the emergence of the basic industries tends to make the whole sector more energy intensive. On the other hand, higher oil prices have provided the necessary incentive for fuel substitution and conservation. The evidence collected suggests that future industrial output will be at least as energy intensive as it is now (based on the increasing share of the energy-intensive industries) but less intensive in petroleum products, due especially to substitution with natural gas. Other forms of substitution, of the kind found in Brazil, are neither capital intensive nor cost effective at current world oil prices. Therefore they are likely to be reversed in the presence of abundant and inexpensive fuel oil.

Transportation

While energy use in the industrial sector has shown a fairly high degree of adaptation to changes in energy prices, the transportation sector appears to be less flexible. Except in the Brazilian market, it is less amenable to fuel substitution.

There are clear differences in the nature of adjustment observed in the two major classes of vehicles: a) automobiles and b) trucks and buses.

The predominant feature in the automobile fleet in the countries studied is the nearly continuous increase of the number of cars per capita, a consequence of rising incomes and, in many cases, of the ample availability and declining real prices of domestically produced vehicles.

That trend is strong in all of Latin America, where the car fleet grew at an average yearly rate of 9.7% between 1970 and 1983, which is far in excess of the 2.5% growth rate of population during the same period. Although the growth in car ownership was clearly disrupted by the recent recession, there is no indication of saturation of the automobile market. On the contrary, in face of the high inflation rates prevailing most everywhere in the developing world, the purchase of durable goods (especially cars) is seen as one of the most available shelters against currency devaluation.

The ownership of cars is much higher in Latin America than in LDCs on other continents. At 50 cars per 1000, it is nearly four times higher than in Asian LDCs (13 per 1000). This is due to a higher level of urbanization, to the greater distance between urban centers, and to a development process designed to rely on motor vehicles.

Although the purchase and use of cars in the studied countries were somewhat dampened by the recent decline in real incomes, there is evidence that automobile use is concentrated in the higher income strata and, therefore, is only weakly affected by the country's overall economic situation.

The energy intensity of the car fleets in different countries covers a wide range. At the high end is Venezuela, where fuel consumption is around 4000 liters per car per year. At the low end there is Brazil, with a specific consumption below 1400 liters per car per year. The difference is largely due to the composition of the car fleet: in Venezuela, nearly half of the cars still have eight cylinders, consuming an average 5000 liters per year, while in Brazil the higher price of imported petroleum has, for many years, led to the production of smaller and more efficient vehicles. Also contributing to the lower gasoline intensity in Brazil is the large availability of alcohol made from biomass as an alternative to gasoline for automobiles.

Fuel use in freight transport differs from that of automobiles in that there is, to a greater extent, the possibility of substitution between gasoline and diesel oil. In many of the countries studied, changes in domestic pricing policies have caused an increased dieselization of the truck fleet. As the international price of oil increased during the 1970s, some governments chose to pass most of the price increase to gasoline, in order to allow for a more gradual increase in the price of diesel and avoid passing the full impact of higher energy prices to the costs of the products shipped by truck. That type of policy was followed in Argentina and Brazil. In the countries that adopted that kind of pricing policy, the diesel truck fleet has outgrown the gasoline units since 1978, and the use of diesel oil has increased with respect to that of gasoline.

That pattern of pricing and substitution, however, is found only among the non-exporters of petroleum. The oil-exporting countries have not, in many cases, brought the domestic price of fuels up to the opportunity cost of petroleum, therefore providing no incentive for conservation or substitution. The differences in pricing policy are clearly reflected in the structure of fuel use. In Argentina and Brazil, energy use in transportation is evenly divided between gasoline and diesel. By contrast, gasoline accounts for 60 percent of transportation energy use in Mexico and a high 80 percent in Venezuela, where most of the smaller trucks and buses run on gasoline.

Freight and passenger transport also differ in their response to overall economic conditions. Some of the countries studied showed a decline in the fuel intensity of the transportation sector during the recession years. That is mostly due to the low levels of industrial activity, which, in turn, reduce demand for freight transport.

The transportation sector is, by nature, so dependent on liquid fuels that pricing policies alone are unlikely to produce permanent declines in the aggregate petroleum intensity of the sector. Any rapid reduction in the intensity of use of gasoline and diesel would require, besides a coherent pricing policy, measures to encourage the production of smaller and more efficient cars, as well as better vehicle maintenance. In Brazil, much of the reduction in gasoline use was achieved through mandated conservation, by requiring that gasoline stations remain close on weekends. In the absence of such measures specifically aimed at improving vehicle efficiency, most countries will continue to consume at the levels presently observed.

Residential

In contrast with the savings sometimes observed in other sectors, the petroleum intensity of household energy use has increased in all the countries studied. This characteristic of residential energy use is due mostly to two factors: a) urban population growth and b) fuel substitution. Due to its direct dependence on the rate of (urban) population growth, energy use in the residential sector is largely independent from each country's overall economic performance. Typically, residential energy use in the countries studied has grown at an average yearly rate around 3 or 4 percent, even in the presence of economic recession.

Growth of urban population has far exceeded that of the total population. In Latin America, urban population increased at an average yearly rate of 4 percent between 1960 and 1984, while the rate for total population was 2.5 percent.

Urbanization is accompanied by a decline in the convenient availability of wood and its replacement with LPG for cooking, as well as the substitution of electricity for kerosene used for lighting. The effects of that process are clearly seen in the rising use of LPG and electricity per household.

This pattern of substitution is often accompanied by a decline in total energy use, most of it due to the higher efficiency of LPG with respect to wood. The actual amount of wood used in the residential sector is largely unknown. Better estimates are necessary in order to assess more accurately the process of deforestation, as well as to gauge the potential expansion of demand for LPG as the process of urbanization progresses. Few countries provide estimates of the amount of wood used in the residential sector; those estimates that exist are subject to significant imprecision because the use of wood takes place primarily in the rural areas, in a dispersed form, with no register of the amounts actually gathered. The existing estimates are of the *delivered* energy; that is, they do not take into account the efficiency of use, which is typically low, in the range of 5–15%.

Power Generation

The differences in energy use between exporters and non-exporters observed in the industrial and transportation sectors are not present in the power generation sector. In this case, the fuel use patterns are dictated primarily by two factors: the price of fuel oil and the availability and cost of alternative domestic fuels.

The higher petroleum prices enhanced the competitiveness of hydroelectricity and natural gas, both of which increased their participation in electricity generation for the region as a whole. Natural gas, which was gaining a higher share of the power-generation market even before the 1978–79 increase in the price of oil, expanded its market share at a faster rate, especially in Argentina and Venezuela. In Brazil, most of the discoveries of new gas reserves are quite recent, and that fuel has had no impact on electricity generation so far. The country continues to rely almost exclusively on hydroelectricity, as it has done for more that three decades.

Despite the more prominent role of non-petroleum fuels, there is evidence that the declining price of petroleum and the existence of surpluses of fuel oil (true for all four countries) are having an impact. Hydroelectric projects, which are highly capital intensive and require several years of construction work, have been delayed in Argentina and Venezuela. In fact, there has been an increase in the use of petroleum products for power generation in Venezuela since 1979, caused by the existence of surpluses of fuel oil and diesel.

Both coal and nuclear power should continue to play a marginal role in electricity generation in the region. There is no evidence of higher use of coal in power plants in any of the countries studied. Although the region possesses substantial deposits of high-grade coal, their exploration has been deferred, and a higher priority has been given to the development of petroleum and natural gas reserves. The emphasis given to nuclear programs in Brazil and Argentina in the 1970s has subsided. The prospect for participation of nuclear power in electricity generation has been weakened by the high cost of the technology, safety problems, and the availability of domestic alternatives.

PLANNED ACTIVITIES FOR FY 1986

During the next fiscal year, we expect to pursue the following activities.

Integrated Assessment: Following the completion of summary profiles for four countries (Argentina, Brazil, Mexico, and Venezuela), we will produce an integrated assessment of the structure of energy demand for the region, emphasizing the changes in end-use patterns caused by the price changes of 1978–79.

Study of Oil-Exporting Countries: In the last three years, government agencies in Mexico and Venezuela have shown a growing interest in conservation and substitution policies, especially in order to promote a more rational use of their petroleum resources. Whereas most of the oil-importing LDCs made policy adjustments in response to the price increase of 1978–79, the oil exporters are contemplating conservation policies in response to a financial crisis which started in 1982. Slack demand for oil and declining prices have reduced the inflow of foreign exchange in those two countries and have contributed to produce a massive external debt. We intend to conduct a study of the balance between the domestic petroleum market in Mexico and Venezuela and the volume of petroleum exports necessary to finance their economic development.

Colombia: We will expand the sample of countries studied by writing a country profile for Colombia. We will also add that country to our data base, collecting and organizing the information on energy demand and the structure of economic activity.

Outlook for Oil and Energy Demand in Asia*

Jayant A. Sathaye and Melchor Guererro

During the past two years, the International Energy Studies Group at the Lawrence Berkeley Laboratory has analyzed in detail energy demand patterns in 13 developing countries that account for most of the increase in world oil demand.† In 1983 the Asian countries in the study used 293.8 MTOE of commercial energy, of which 135.5 MTOE were oil products. But the intensity of oil use in these countries changed; if the 1978 patterns had held through 1983, oil use in East and South East Asia would have been 23.0 MTOE higher than it actually was, but in S. Asia, changing intensities led to much smaller oil savings (Figs. 1, 2, and 3). *For all these countries, oil use will increase in the future,* because of economic growth, even if oil intensities or shares continue to fall.

Because of many differences in the economies, the near term outlook for oil and energy demand is different for East and South East Asia than for South Asia. The long run outlook, however, is similar across Asia. The near term outlook calls for substitution and improved demand management in most of the countries in East and South East Asia. This means that the share of oil in energy demand in this region will decline, but the total demand for oil will increase, even if economies grow at a slower pace than the average annual growth rates of 5% to 10% in the 1970s. In the long run, oil demand may increase after the potential for substitution is exhausted.

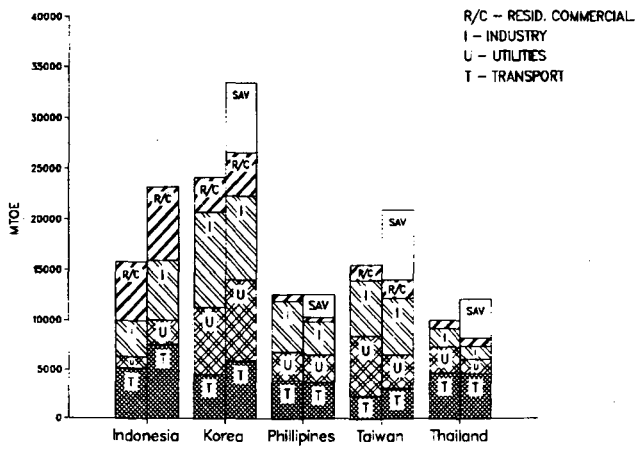

Figure 1. Oil backout in Asia, 1978 vs. 1982–83, by sector. (XBL 862-445)

*This work was supported by Contributions from Exxon Corporation (and Esso Eastern), the Standard Oil Company of Ohio, Chevron Inc., and Statoil of Norway through the U.S. Department of Energy under Contract No. DE-AC03-76SF00098. The project also received assistance from Scallop Corp., NY.

†These are Argentina, Brazil, Mexico and Venezuela in S. America, and Bangladesh, India, and Pakistan (S. Asia) Indonesia, Malaysia, Philippines, and Thailand (S.E. Asia), and Korea and Taiwan (E. Asia) in Asia.

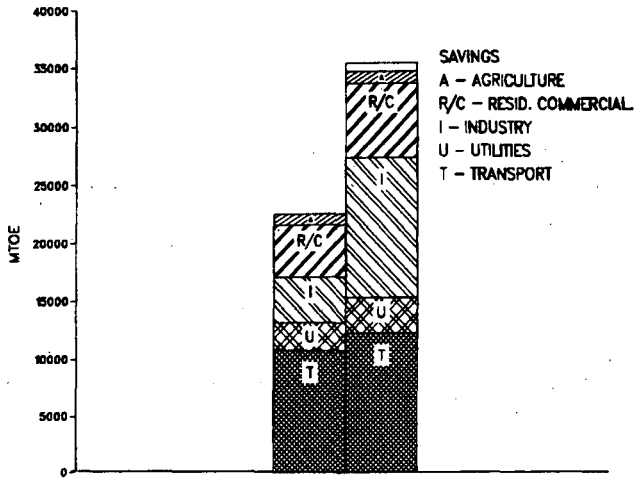

Figure 2. Total oil backout in India, 1978 vs. 1983, by sector. (XBL 862-444)

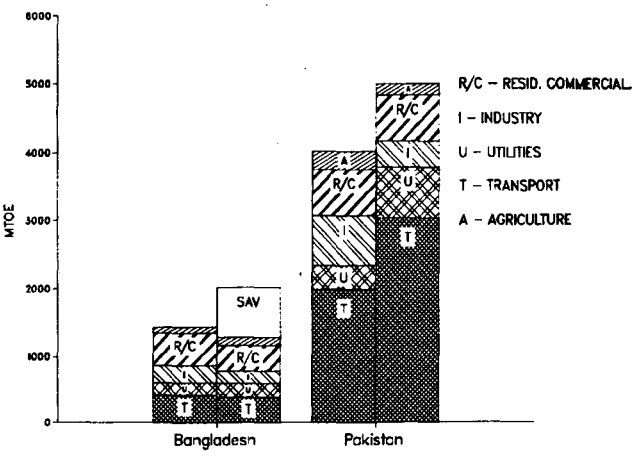

Figure 3. Total oil backout in Bangladesh and Pakistan, 1978 vs. 1983, by sector. (XBL 862-446)

ACCOMPLISHMENTS DURING FY 1985

In FY 85, we addressed the quantification of the oil backout in the Asian countries since 1978. We wrote country reports highlighting the nature of oil use in each of the four major sectors—industry, power, transport and households.[1–9] These reports describe the structural changes prompted by each country's desire to reduce the demand for oil. The changes varied between sectors from substitution, primarily in the industrial sector, to reduced, and perhaps more efficient, use of oil in the transport sector.

We set up a data base for each of the nine Asian countries. It contains information and data on both energy use and economic and structural activity for each sector, from as far back as 1970 to 1983 or 1984. The data base is in standard IBM PC format.

Background

Economic development in Asia has been rapid in the past two decades. Even after the first oil price increase, economic development did not slow and was accompanied by an increase in both the share and absolute level of oil use. After the second oil price increase, economic development slowed in most oil importing developing countries (OIDCs) in East Asia (gross domestic product declined in Korea in 1980–81). This was accompanied by a decline in the share of oil use, as most countries scrambled to find substitutes for oil and to manage energy consumption more effectively. The South Asian countries, however, were relatively insulated from this world recession and were further assisted by transfer payments from their own nationals working in the Middle East. Their economies continued to grow, as did their demand for oil and energy, at annual growth rates of around 5%. Thus the energy and economic development of South Asia and East or South East Asia differed after 1978.

In South Asia, oil is used for the most essential needs, yet there is still room for improved management of its use. This may not occur unless the price of middle distillates, the major petroleum products in use, is increased to provide an incentive for improved use. Nevertheless the population base is enormous. The outlook is, therefore, for annual growth in oil and energy consumption to exceed 5%. This translates into increases in oil demand in excess of 50,000 BPD annually. In the rest of Asia the growth rates may be lower, but the total volumes are as high or higher.

Industry

Industry in Asian countries accounts for over 50% of the modern or "commercial" energy use. Prior to the first oil price increase, much of industry in East and South East Asia was powered by oil, which was inexpensive, convenient to use, and easily available on the world market. Only in South Asia did the economies rely extensively on energy from sources other than oil. The result was that after 1978, the most oil-dependent countries in E. and S.E. Asia had to move rapidly away from oil. These countries reduced the intensity of oil and energy use through energy management, something at which

South Korea was particularly successful. Most S.E. and E. Asian countries also employed alternative domestic or imported fuels, such as coal, natural gas, and nuclear fuel, for power generation.

Korea, Taiwan, and the Philippines, however, do not have easy access to natural gas. Much of the substitution away from oil is limited to the use of coal in cement and steel plants. In Indonesia, Malaysia, Pakistan, Bangladesh and Thailand, on the other hand, domestic natural gas is likely to provide most of the future industrial energy use and even fuel homes. Most power plants in East and South East Asian countries are expected to continue the switch from oil to coal, natural gas, hydro, geothermal and nuclear energy. This substitution should be completed by 1987–88. The share of oil would then reach its lowest point unless the price of oil rises to make further improved management of its use more attractive. Barring this possibility, the share and absolute use should increase. If the oil price increases further, the oil share would decline, but absolute oil consumption still may increase.

Transport

The demand for fuels in the transport sector is driven by the need for personal transport, which is being met by increasing numbers of autos and motorcycles, and by expansion of bus and train services. The first two modes drive gasoline demand, while the latter two, combined with trucks, as well as rail freight, drive diesel demand. The ownership of cars is extremely low, e.g., around 1 to 2 per thousand persons in South Asia, and that of motorcycles is high in most of Asia compared to that in Latin America. These numbers will rise. The rapid increase in car ownership, brought about by liberalized granting of licenses for their manufacture in Korea and India, is a preliminary indication of this trend. In the short run, the growth in freight transport aided by the subsidized price of diesel compared to the international price and the high gasoline price would ensure that diesel demand continues to grow rapidly. This has already caused a mismatch between the refinery supply mix and the demand slate. In the long run, however, acquisition of cars and motorcycles will drive gasoline demand in these countries ahead of that for diesel.

Households

In households, demand for fuels is driven primarily by the need for cooking, lighting and comfort. In the lower income South Asian countries, cooking and lighting needs predominate. In South Asia and Indonesia, traditional fuels supply as much as 80% of the household energy needs. The level of use is sensitive to the price of kerosene, their petroleum substitute, which together with LPG forms the bulk of commercial fuels used for cooking. Lighting and comfort needs in cities are met through the use of electricity, and in rural areas through the use of kerosene for lighting and occasionally for refrigeration, but the overall level of electrification is very low. The demand for kerosene and LPG is likely to increase as more households move away from traditional fuels in these countries. The use of electricity is also spreading rapidly as households acquire appliances to meet new services, such as refrigeration and air-conditioning. In middle-income countries, such as Taiwan (and Singapore, which we have also examined), about a quarter of the homes had air-conditioners by 1983. Saturation of refrigerators was close to 90%. Korea and the larger cities of the other Asian countries are approaching these levels. As this development spreads to the remaining Asian countries, however, demand for all forms of energy for households, and a parallel increase for electric power and even some oil products or gas for the growing commercial sectors of these countries, will push energy and oil demand upwards even more.

Conclusion

The economies in Asia are younger than those in Latin America and hold potential for continued rapid economic growth in the coming decade. Meeting the energy needs of these economies will be a critical to maintaining healthy rates of economic development and the social stability that this development assures. The middle-income countries in the region are determined to diversify their mix of energy supplies and to institute measures to better manage their use of energy. Their demand for oil will still increase in the long run with economic growth.

The lower income countries in this region, along with Indonesia, have large populations, which are perennially short of electricity and kerosene for household use.[‡] If the rural consumer were to consume as much kerosene as his urban counterpart in India, 11.6 liters per capita in 1978–79, it would add 62,000 BPD to consumption of petroleum products. Similar figures would result from an increase in

[‡]Estimates for India suggest that economic growth *rates* would rise by as much as 30% in the short run, if adequate power were available for industry.

automobile use. Despite the low level of personal consumption, the large population base combined with the promise offered by recent rapid economic growth rates may lead to unsustainable consumption of oil in the near future. Thus, the low levels of use today in S. Asia and much of S.E. Asia, coupled to large populations, pose just as imposing a challenge on the world's energy markets as does the continued expansion of the more mature economies of N. Asia. Meeting this challenge is a major task for the energy industries and concerned governments in the Asia-Pacific Region.

PLANNED ACTIVITIES FOR FY 1986

During the past year, the work on this region focused on background energy-economy reports on each of the nine study countries and an analysis of the backout of oil during the period after 1978. The work this year will focus on examining the reasons for the expected upturn in the demand for oil, the magnitude and feasibility of this upturn, the ability of the economies to sustain the increasing demand for oil and the policies that might be adopted for its management. Additionally, the work will focus on studying new countries, including those in the Middle-East and Africa, whose patterns of demand and economic development are significantly different from those studied thus far.

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Changing Energy Use Patterns in Mexico*

Andrea N. Ketoff, Andre Ghirardi, and Peter Goering

The objective of this study is to assess the structure of energy demand in Mexico and its evolution during the last decade. This analysis is to be integrated with a larger comparative study of patterns of energy demand in 15 countries of Latin America and Asia.

The results of the assessment indicate that the efficiency of energy use in Mexico is rather low (in comparison with the other countries studied so far) and that the current climate of economic recession may provide the opportunity and the incentive for the definition of demand-oriented energy policies.

As in the other studies in this series, the following analysis uses a bottom-up approach, that is, characterizing the patterns of energy use according to changes in *structure* (e.g., number of cars, tons of steel) and *intensity* (i.e., unit consumption). This approach provides a better understanding of the factors that determine energy demand, highlighting the characteristics of specific sectors. It also provides the basis for inter-country comparisons of energy use indicators, thus helping the assessment of future energy demand for regions or groups of countries.

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ACCOMPLISHMENTS DURING FY 1985

In FY 1985, this project compiled a consistent set of data on energy demand and sectoral structure and produced a summary assessment of the relationship between sectoral energy use and economic growth in Mexico during the last 10 years. The compilation of data, although not yet complete, has already produced a body of information that is unique in the uniformity with which it treats each of the main sectors of the economy and in the consistency with which it presents the hypothesis used to generate estimates of individual data points. There are no other sources containing that type of information that have been both validated by cross-checking sources and condensed into parallel time series.

Summary Assessment of Energy-Use Patterns

Oil accounts for more than 70% of Mexico's commercial energy use. The dependence on oil has been increasing gradually as petroleum resources have been the basis for the country's economic growth, both as a source of energy and, after 1977, as a source of foreign exchange.

The perception of an abundance of domestic fuel resources and the resulting low energy prices have served as a disincentive to the exploration of non-petroleum energy sources as well as to the pursuit of higher efficiency in the use of energy. As a result, there has been a decline in the efficiency of energy use, most noticeably in the period of growth ranging from the mid-1970s until 1981.

The drop in international oil prices and in OECD oil demand during the 1982 recession hit Mexico particularly hard, since 75% of government revenues were generated by oil exports, primarily to the United States. The current economic reality of oil revenues drained by the debt service payments and of continuing recession is motivating a growing interest in energy conservation and in a demand-oriented energy policy.

The discovery of vast oil reserves in the mid-seventies in the Bay of Campeche brought about an upturn in the Mexican economy. Within a period of five years, proven petroleum reserves increased from 6 to 72 billion barrels, production tripled, and oil exports increased ten-fold, reaching 600 million barrels per year and replacing agriculture as the country's main source of foreign exchange.[1]

In the presence of these changes, aggregate energy demand indicators showed a steady growth between 1970 and 1981.

Some of the main characteristics of that growth period were:

- Energy use per capita increased 80% between 1970 and 1982 and leveled off in the two following years.
- The use of *energy* relative to gross domestic product increased 36% in the same period.
- The use of *oil* relative to GDP increased 49%.

Despite the increase in the overall energy-intensity of the economy in recent years, there is no sign of that the increase was directly related to the increase in petroleum revenues, contrarily to what we observed in Venezuela. Also in contrast to most other major Latin-American economies, there is no evidence of substantial fuel substitution.

In order to understand the implications of the trends identified above, we must look at the underlying structure of energy use in the country. Table 1 shows a disaggregation of energy use in 1983, by fuels and by major end-use sectors.

Industrial Energy Use

Industrial energy use is dominated by three sectors: Iron & Steel (27%), Chemicals (11%), and Cement (9%). Combined with three other sectors—Sugar, Paper & Pulp, and Glass, these industries account for 61% of total commercial energy demand of the sector in 1981. Bagasse, used exclusively in the sugar industry, represents another 7% of total industrial energy use.

The energy and petroleum intensities of the industrial sector varied only slightly (less than 10%) between 1970 and 1981. There was, however, a remarkable drop in natural gas intensity of the sector (−20% since 1970), in contrast with the sharp increase registered in other Latin-American countries, most noticeably Argentina and Venezuela. Although many industries (e.g., cement production) are equipped with dual-firing capability, the price difference still favors the use of fuel oil over natural gas.

The level of efficiency of industrial processes is uneven among subsectors, influenced by the quality of the imported technology as well as by the age of the production plants. The energy-intensity of cement production is comparable with the levels observed in OECD countries, but the same is not true for the sugar or the paper industry, two of the largest energy users in the sector. Comparisons of specific consumption (energy/tonne) of the principal energy-intensive processes with those of other developing as well as industrialized countries suggest that, although Mexico does not have the worst per-

Table 1. MEXICO—Fuel distribution by sectors, 1983.

	Industry	Non-Energy	Res.-Comm.	Agricult.	Transport.	TOTAL
OIL, 10^{12} kcal	61.15	48.84	68.47	1.62	262.67	442.75
—, % of sec.	25.6	42.3	41.3	29.8	99.8	56.2
—, % of fuel	(13.8)	(11.0)	(15.5)	(0.4)	(59.3)	(100)
NAT. GAS, 10^{12} kcal	93.51	66.53	6.25	—	—	166.29
—, % of sec.	39.2	57.7	3.8			21.1
—, % of fuel	(56.2)	(40.0)	(3.8)			(100)
COAL, 10^{12} kcal	38.19	—	—	—	—	38.19
—, % of sec.	16.0					4.8
—, % of fuel	(100)					(100)
WOOD,BAGASSE, 10^{12} kcal	15.47	—	72.16	—	—	87.63
—, % of sec.	6.5		43.6			11.1
—, % of fuel	(17.7)		(82.3)			(100)
ELECTRICITY, 10^{12} kcal	30.42	—	18.75	3.82	0.45	53.44
—, % of sec.	12.7		11.3	70.2	0.2	6.8
—, % of fuel	(56.9)		(35.1)	(7.2)	(0.8)	(100)
TOTAL, 10^{12} kcal	238.74	115.37	165.63	5.44	263.12	788.30
—, % of sec.	100	100	100	100	100	100
—, % of fuel	(30.3)	(14.6)	(21.0)	(0.7)	(33.4)	(100)

Source: CFE.

formance in energy use per unit of output, much can be done to improve the energy productivity.

The steel industry is the most energy-intensive sector in the Mexican industry. In 1981, steel accounted for over 27% of industrial energy use. Steel production has grown strongly in the last 15 years, going from 3.9 million tons in 1970 to a maximum of 7.7 million tons in 1981. The period of recession that started in 1982 resulted in lower production in 1982 and 1983. By 1984 there were indications of a possible recovery, as output increased to 7.5 million tons in 1984.

The chemical industry, led by basic organic chemicals, experienced high growth throughout the 1970s and early 1980s, with output increasing at an yearly average of 15 percent. Availability of cheap natural gas as a feedstock has pushed the petrochemical subsector to even higher growth rates. In 1981, natural gas accounted for 57% of the purchased energy used in the chemical industry and oil another 28%. Purchased electricity was about 8% and cogeneration another 5%. Since most of the chemical industry plant is fairly new, energy intensities in it are closer to world standards than they are in other sectors. A high percentage of the energy used in the industry is for process heat, suggesting the possibility of efficiency improvements through cogeneration.

Cement output grew steadily from the 1950s until the current recessionary period, while the petroleum intensity of this sector declined over 20% since 1968 due to modernization. At the same time electricity use has increased, but electrical energy intensity is still only 10% of petroleum intensity. The trend of petroleum substitution by electricity is likely to continue in the near future. Growth in future cement production, as with steel production, will be closely linked with economic development.

Transportation

Transportation uses more energy than any other sector (40% of total). That share is still increasing, driven by the growth of the vehicle fleet, which is driven, in turn, by growth in car ownership per capita. This indicator grew 9% per year from 1970 to 1981 but stagnated in the following years, as a consequence of declining personal incomes.

Gasoline consumption per car (~3000 liters/car) is among the highest in Latin America. Although information about the last 3 years is still sketchy, there is indication that as incomes declined and gasoline prices reached international levels, the use of private cars, and gasoline use per car, was reduced markedly. The price increase also resulted in an

unexpected growth in the illegal use of LPG in cars. LPG prices are kept artificially low, since that fuel is meant primarily for cooking.

Gasoline is used in almost 100% of private cars (no diesel cars are sold) and in part of the truck and bus fleet, despite the considerable price difference, particularly until 1981. There is evidence that some substitution of diesel for gasoline occurred in the 1970s. However, the share of gasoline in the total energy supply of the sector is still in excess of 60 percent, compared to 50 percent in Argentina and Brasil.

The Residential Sector

Energy demand in the residential sector shows large growth potential, due to the high rates of growth of population and urbanization in Mexico. That is particularly true for cooking fuels, since they represent the largest share of household energy use. While electrification is relatively high (more than 80% of households), one-third of Mexican families still rely on wood as the main fuel for cooking.

Residential electricity use per capita is currently 180 kWh/year (23 percent lower than in Brasil), although it increased almost 60% between 1970 and 1983. About two-thirds of the population lives in areas where no heating or cooling is needed. Air conditioning is diffused principally in the dry Northern regions, where subsidized electricity prices during the summer months (since 1973) have led to a 230% increase in electricity demand per customer between 1973 and 1980.[2]

The increasing levels of appliance ownership will be one of the main forces driving electricity demand. Refrigerators are the most rapidly diffusing energy-using devices in Mexican homes, although their saturation remained under 30% in 1984. The existence of a large market for electrical appliances also presents an opportunity for the effective implementation of conservation policies, possibly through the establishment of standards for appliance efficiency.

Wherever gas is used for cooking, LPG is generally the fuel of choice. The use of natural gas remains limited to the few urban areas served by the gas network, and its widespread distribution is restrained by the fact that the housing stock consists mainly of one or two story homes, which increases the cost of distribution networks.

The Petroleum Industry

Although for purposes of comparison with other countries this study is aimed primarily at final energy demand, it should be noted that the Mexican petroleum industry presents a better opportunity for energy conservation than any other sector of the local economy. There is evidence that the overall efficiency of the oil industry has been declining in recent years, reaching levels much below those of most oil-exporting countries.[3] The probable causes are to be found in poor integration and maintenance of the refining system, as well as the internal pricing structure within the oil industry: products are transferred at no cost within Pemex, and accurate accounting has been established only in recent years.

Pemex has launched a plan for energy saving, particularly focused on natural gas. This calls for better combustion control and maintenance. In 1984, the first phase of this plan—including reductions in flared gas in fields—has produced savings estimated at 1.2 MTOE (Million Tons of Oil Equivalent).[4]

Electricity Generation

Electricity generation increased nearly threefold between 1970 and 1983. Annual growth continued at 8–10 per cent per year until 1983, when it was reduced to 2%.

Thermal generating capacity has grown faster than hydroelectric generation during the last decade. The contribution of hydroelectric plants, which provided more than half of total electricity generated in 1971, dropped to 37% by 1982. Unlike all other Latin-American countries, hydroelectric generation in Mexico is not expected to grow considerably, due to the high capital costs and the limited number of unexploited sites for large dams.

Despite the existence of dual-firing capability developed to guarantee the use of the natural gas associated with oil deposits, the natural gas share of thermal generation dropped from 40 to 18 percent between 1970 and 1984. That appears to have been caused mostly by the difference in price and the existence of surpluses of fuel oil.[4,5]

Coal and geothermal sites have been developed as alternatives in recent years, although they have not resulted in major changes in the overall structure of electricity generation. Geothermal capacity is expected to reach 600 MW by 1990, coal 1200 MW. Construction of more than one of the many nuclear power plants planned in the late seventies nows appears highly unlikely because of the increasing costs and the difficulties in procuring foreign exchange.

PLANNED ACTIVITIES FOR FY 1986

During the next fiscal year, we expect to examine the opportunities for improving energy efficiency in

the Mexican Public Sector, in collaboration with the Mexican Department of Energy (SEMIP). This sector is important to Mexico's ability to make better use of its resources and to have oil available for export. We will analyze the patterns of energy use in the state-owned industries—the energy sector (oil and electricity), the public transportation system, and the government buildings. This study will help identify the areas and conditions for cooperation in the areas of technology transfer and policy formulation.

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Residential Energy Use in LDCs: Guidelines for the Analysis of Low-Income African Countries*

Gianfranco Rizzo,† Andrea Ketoff, and Andre Ghirardi

There is much concern today about the impact of higher energy costs on the economies of the oil-importing Less Developed Countries (LDCs), particularly the low-income countries whose development is further restrained by the increasing burden of providing energy resources.

In these countries, energy demand is typically dominated by the residential sector, which sometimes accounts for as much as seventy percent of national energy use. Most of the demand in this sector is met with non-commercial fuels (fuelwood and charcoal), but as urbanization increases and lifestyle improves these traditional fuels are replaced by commercial sources, namely kerosene, LPG, and electricity.

ACCOMPLISHMENTS DURING FY 1985

In order to illustrate the patterns of energy use and fuel substitution in Africa, we have studied a sample of eleven countries, selected according to the level of economic development and the availability of information.

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In most LDCs, the lack of reliable data is a severe limitation to the scope and accuracy of analyses of residential energy markets and to the adoption of demand-oriented policies. While there is usually some record of transactions involving commercial fuels, the use of non-commercial fuels is often gauged by means of broad estimations of the various forms of biomass collected by each household. More precise estimates of the use of these non-commercial fuels can only be generated by local surveys of the fuel-gathering activities.

There are few complete surveys of household energy use in African countries, but a number of small-scale studies have started to produce some information on the profile of energy use in that sector. In their review of studies on West African countries, Kahane and Lwakabamba address some of the problems created by the diversity of these studies, and the difficulties to achieve consistent international comparisons that will help understanding the determinants of residential energy demand.[1]

For this study, we selected countries for which some sectoral data had been already collected or estimated in previous studies.[2–4] These are: Angola, Botswana, Kenya, Lesotho, Malawi, Mozambique, Sierra Leone, Swaziland, Tanzania, Zambia, and Zimbabwe. All these countries are in South and East Africa, except for Sierra Leone, which was selected here because of the extensive data-gathering performed there.

Three main features emerge from the analysis of residential energy demand in these countries and appear to be typical of most low-income LDCs: the high share of residential energy use; the small (but growing) use of commercial fuels; and the predominance of cooking as the most energy-intensive activity.

The high share of residential energy use, over the total national consumption, is evident in all cases. If we include non-commercial energy sources in the accounting, household primary energy use is over 50% of total national consumption in all but one (Swaziland) of the countries studied, reaching 75% in Mozambique, Lesotho, and Sierra Leone (Table 1). Unlike the LDCs in other regions of the world (e.g., Latin America), there is relatively little fuel use in industry and transportation. In most of the countries studied, the level of industrialization is low, and the use of trucks, buses and automobiles is limited by the poor infrastructure of road transport.

Clearly, the residential sector should be the focus of demand-oriented policies, not only because of the threat of deforestation and biomass-fuel shortage, but also because that sector will continue to be the main determinant of fuel consumption in the immediate future.[5,6]

The second characteristic, the high use of non-commercial fuels, is closely linked with the demographic concentration in rural areas. Whereas the use of oil, gas and electricity is growing steadily in urban areas, three-quarters (or more) of the population lives in rural areas, where energy is supplied almost exclusively by fuelwood and agricultural residues. Nowhere in the region studied is the use of commercial energy more than 20 percent of the total, with the average being around 10 percent (Table 1).

Even in urban dwellings, the share of non-commercial fuels varies between 60 and 90 per cent, except for Lesotho and Swaziland, where coal is widely used for heating, covering as much as 50% of urban demand.

Although the use of kerosene and electricity has become more frequent with increasing urbanization, wood-burning backup systems are still kept in use. A typical example of that pattern of fuel use is found in Sierra Leone, where fuelwood remains as a secondary energy source in all urban households that use charcoal or kerosene as their principal cooking fuel (50% of the dwellings).[2]

A recent survey in that country shows that the use of fuelwood for cooking is entirely discontinued only in households that cook with LPG. The survey results also show a clear pattern of fuel substitution as a function of household income. As incomes grow, so does the use of LPG and electricity, replacing fuelwood, charcoal, and kerosene. If the above findings are representative of the typical patterns of fuel substitution, they would have important policy implications. They show that only LPG provides complete displacement of fuelwood for cooking, that is, the problem of deforestation by wood gathering would not be eliminated by promoting higher use of kerosene (or charcoal).

Finally, there is the issue of the predominance of cooking as the most fuel-consuming task in households. Its share of total use in the countries studied ranges from 20 to 90 percent, with the higher values generally observed in rural areas (Table 1).

It should be kept in mind, however, that the label "cooking" really encompasses a number of functions in African households, including water heating and space heating, when needed.[7] The most widely used form of cooking, in both rural and urban areas, is the open-fire burning of fuelwood, although charcoal and kerosene are *also* used in higher income urban households (electric hot water supplements these fuels for water heating in the high income urban households).

Table 1. Household energy use in African countries.

	Angola 1980	Botswana 1980	Kenya 1980	Lesotho 1980	Malawi 1980	Mozambique 1980	SierraLeone 1982	Swaziland 1980	Tanzania 1980	Zambia 1980	Zimbabwe 1980
Population, 10^6	7.10	1.00	15.90	1.30	6.10	12.10	3.35	0.63	18.70	5.80	7.40
Urban pop, %	21.1	13.4	...	9.4	7.3	7.8	25.0	14.7	7.3	42.0	22.7
GNP/cap (US Doll.)[a]	470	910	420	420	230	230	280[b]	680	280	560	630
Total E. Use, PJ	105	22	332	24	165	282	46	24	439	150	244
Urban E. Use, %	11.8	9.1	10.8	11.1	7.3	4.2	22.6	10.0	4.5	20.5	8.9
Non-Comm.Fuels, %	74.3	54.6	71.7	75.0	91.0	88.0	78.8	62.5	90.4	57.4	51.3
Resid. E. Use, PJ	59	11	194	18	68	215	32	5	285	73	112
(Resid./Tot., %)	(56.2)	(50.0)	(58.4)	(75.0)	(41.2)	(76.2)	(68.1)	(20.8)	(64.9)	(48.6)	(45.9)
Comm.Fuels, %	3.4	9.1	5.1	11.1	0.7	1.4	4.2	20.0	1.4	4.1	4.4
— *Oil, %*	*2.6*	*4.2*	*4.0*	*4.9*	*0.4*	*1.0*	*3.5*	*4.8*	*1.1*	*1.0*	*1.0*
— *Elec, %*	*0.8*	*2.6*	*1.1*	*0.4*	*0.3*	*0.4*	*0.7*	*3.6*	*0.3*	*3.1*	*3.0*
— *Coal, %*	—	*2.3*	—	*5.8*	—	—	—	*11.6*	—	—	*0.4*
Non-Comm. Fuels, %	96.6	90.9	94.9	88.9	99.3	98.6	95.8	80.0	98.6	95.9	96.6
— *Fuelwood, %*	*84.2*	*90.1*	*79.0*	*54.5*	*92.6*	*89.8*	*89.1*	*75.9*	*92.8*	*76.9*	*95.0*
— *Charcoal, %*	*8.5*	—	*11.3*	—	*2.5*	*0.5*	*6.5*	—	*3.0*	*17.4*	—
— *Other Biomass, %*	*3.9*	*0.8*	*4.6*	*34.4*	*4.2*	*8.3*	*0.2*	*4.1*	*2.8*	*1.6*	*0.6*
Comm. Urban, %	21.4	34.8	26.8	83.4	9.7	15.3	11.7	89.0	20.8	12.6	39.5
— *Oil, %*	*14.6*	*10.6*	*17.1*	*23.9*	*4.6*	*10.0*	*9.1*	*20.5*	*14.3*	*3.2*	*5.2*
— *Elec, %*	*6.8*	*12.1*	*9.7*	*4.9*	*5.1*	*5.3*	*2.6*	*24.6*	*6.5*	*9.4*	*33.0*
— *Coal, %*	—	*12.1*	—	*54.6*	—	—	—	*43.9*	—	—	*1.3*
Non-Comm. Urban, %	78.6	65.2	73.2	16.6	90.3	84.7	88.3	11.0	79.2	87.4	60.5
— *Fuelwood, %*	—	*65.2*	*14.1*	*16.6*	*48.4*	*75.8*	*78.3*	*11.0*	*43.0*	*16.7*	*60.5*
— *Charcoal, %*	*78.6*	—	*59.1*	—	*41.9*	*8.9*	*10.0*	—	*36.2*	*70.7*	—
Comm in Rural, %	1.2	0.6	2.4	5.2	0.1	0.6	2.0	5.4	0.5	1.7	1.0
Urban Resid. E. Use:											
— Cooking+HW, %	88.5	54.5	78.0	18.2	41.3	53.8	79.6	19.2	38.3	70.5	30.4
— Lighting, %	7.7	10.6	10.3	4.9	4.8	6.8	9.2	20.5	11.8	3.9	6.1
— Heating and other, %	3.8	34.9	11.7	76.9	53.9	39.4	11.2	60.3	49.9	25.6	63.5

[a] From World Bank.

[b] 1980 figure.

Due to their prevalence, woodstoves are the primary target of any policy aimed at improving energy use efficiency, as demonstrated by several pilot projects and programs initiated by local and international agencies.

PLANNED ACTIVITIES FOR FY 1986

Comprehensive surveys of appliance saturation and efficiency are usually an impossible task for poor countries with dispersed population. With such quality of data, many of the available modeling tools cannot be applied effectively for policy purposes. Using international comparisons we were able to characterize the factors that are common to the countries sampled, although the detail of information and its reliability is often uneven.

With new support from DOE for 1986, we plan to expand our study to other African countries and to extend our analysis to the other sectors. The literature surveyed allows preliminary estimation of the fuel distribution by principal sectors. In order to perform comprehensive analyses and scenarios, as well as to carry out effective energy planning, statistics on energy use need to be more disaggregated and integrated with economic and price data.

We will carry out this integration in cooperation with other international research institutions (including the Italian National Research Council) and with the direct collaboration of local expert and government authorities.

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Transport Energy Use in Cities of the Less Developed Countries*

Jayant Sathaye and Stephen Meyers

The International Energy Studies Group has been studying the use of energy in the urban areas of Less Developed Countries (LDCs) countries for the last several years. The changes in energy-using capital stock (dwellings, vehicles, appliances) are similar in urban areas of most LDCs. The more advanced LDCs thus provide a clue to the future development of cities in less advanced countries. Since the use of modern fuels is concentrated in the urban area, changes in structure can be used as a guide to future demand for modern fuels in the LDCs.

In FY 1984, we reviewed the use of energy in homes and for transportation in the cities of LDCs. In FY 1985 we expanded the review of transportation energy use to look in more detail at the transportation sector and the potential for growth in this sector. Most of the information we gathered concerns transportation of people rather than goods.

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ACCOMPLISHMENTS DURING FY 1985

A number of transport options (modes) are in use in cities of LDCs. Walking, bicycles, and cycle rickshaws are common forms of transportation. In China, for example, government policy and low income combine to restrict transportation mainly to walking and bicycles (Table 1).[1]

Mass transport is popular and exists in many forms. Along with large buses, smaller private buses and shared taxis are common. The most common form of private transportation is the motorcycle. Ownership of motorcycles has grown rapidly in many places (Table 2).

Members of higher-income households are more likely to own or have access to, and travel by, car. In Malaysia, 40% of the surveyed households reported the car as their mode of travel to work.[2] Among the poor households, very few people used a car, but in the wealthiest group, over 90% did so.

The most distinctive feature of the transportation sector in LDC cities is the rapid growth in use of automobiles. Automobile ownership in develop-

Table 1. Frequency of trips (percent).

	Walking	Bus/Trolley Car	Bicycle	Other
Shanghai	43.2	38.5	13.2	7.8
Tianjin	42.6	10.3	44.5	2.6
Xuzhou	46.5	6.2	44.6	2.7

Source: Yushi and Guangrong (1985).

Table 2. Motor vehicle registration per thousand persons.

	1970		1982	
	Cars	M/Cycles	Cars	M/Cycles
USA	436.4	13.8	540.9	26.0
Argentina	70.6	—	114.9	—
Venezuela	56.1	—	97.1	
Brazil	28.7	—	64.9	—
Taiwan	3.4	47.7	32.4	278.7
Korea	1.9	—	7.8	10.4
India	1.3	1.1	1.5	3.5

Source: Country specific transportation and population statistics.

Table 3. Urban car ownership.

	Population thousands (1970)	Income per capita (1970 US$)	Number of autos per 1000 Population (1970)
Seoul	5536	440	6.3
Calcutta	7402	270	13.0
Bombay	5792	390	13.5
Jakarta	4312	325	18.0
Bangkok	3090	525	49.7
Sao Paulo	8400	785	62.3
Beunos Aires	8400	1800	73.9
Mexico City	8600	1275	78.3
London	10547	2550	222.0

Source: World Bank (1975).

ing countries is much lower than in developed countries, but has grown rapidly since 1970 (Table 2).

Rapid growth in ownership of cars and motorcycles can occur if economic conditions permit. Per capita ownership of cars in Taiwan increased by almost ten-fold during a period of rapid economic growth from 1970 to 1982. In India, the three-fold increase in per capita ownership of motorcycles was primarily due to the government policy of liberalizing the granting of licenses for the manufacture of motorcycles.

Increase in private rather than business car ownership has driven the rapid increase in ownership of cars, though the use of business cars remains common. The share of private cars in Korea and Taiwan increased from 53 and 58 percent in 1970 to 76 and 88 percent, respectively, in 1982.

The level of automobile ownership depends heavily on income (Table 3). Ownership increases with income, unless restrained by government policy to limit imports of automobiles, as in Seoul, Bombay and Calcutta, or by heavy tax on imported cars, as in Jakarta.[3] It is much higher in Latin America than in Asia, even at the same average income level. This may be due in part to government policies limiting or heavily taxing the import of cars. The higher population density in Asia may also encourage the use of motorcycles and public transport. Additionally, the fact that Latin American countries have enjoyed higher incomes for a relatively longer time period may contribute to their higher level of car ownership. Malaysia has had a low population density, a good network of roads, a relatively high per capita income for a long time period, and a relatively unrestricted government policy, all of which have stimulated private vehicle ownership. As a result, car ownership in Malaysia at 74 cars per thousand persons (1982) was very close to that in Latin America.

Within a country, energy use in personal transportation varies enormously among income groups. This is because of the large increase in energy use that comes with automobile ownership. A 1974 survey of household energy use in Hong Kong found a forty-fold increase in per capita energy use for transportation between the lowest and highest income groups.[4] Most of this increase was accounted for by use of gasoline and diesel fuel for private use.

The growing use of cars has an important effect on energy use, since cars use considerably more energy per passenger-kilometer than other transport modes. Energy efficiencies calculated for Hong Kong show the automobile to be 10 to 15 times more energy intensive than buses.[4] In three Latin American countries, automobile transportation is responsible for 65–75% of energy used in passenger transportation, but carry only 25–35% of the total volume of traffic.[5]

The operating efficiency of cars—expressed in terms of amount of fuel use per distance travelled—has been improving in most developing countries. The degree of improvement depends on whether cars are imported, assembled, or manufactured domestically. Those that assemble or manufacture their own cars tend to lag behind. For example, the Ambassador, the most popular model of car produced in India, is of 1960s vintage and has a fuel consumption more than twice that of a comparably sized Japanese or German car (Table 4).[6] In Taiwan, the fuel consumption is between these two extremes, since the cars assembled are of a more recent vintage.

Table 4. Gas mileage of new cars (liters/100 km).

India Ambassador	Taiwan	Japan Corolla	Japan Civic	Germany Rabbit
13.6	8.5[a]	6.0	6.4	6.0

Source: World Bank (1985) and Chang (1985).

[a]Estimate based on data in Chang (1985).

Gains in gas mileage have been achieved through smaller size and improved vehicle characteristics. An estimate for passenger cars in Taiwan was that halving the displacement results in a 45% decrease in fuel consumption per passenger-km.[7] These gains have been partly offset by the growing number of air-conditioned vehicles in some developing countries. On the average, fuel consumption per passenger kilometer is 12% higher for air-conditioned cars than for non air-conditioned cars.

The impact of growing automobile use depends on how well the capacity is utilized. Traffic conditions also affect energy consumption. Congestion, which has become severe in many LDC cities, leads to slower travel and less efficient operation of fuel-powered vehicles. Average trip length is affected by particular features of the urban landscape, such as the degree of urban sprawl. Average trip lengths in Nairobi were reported to be 1.5 to 2.8 miles.[8] Comparable figures for Mexico City, which is larger than Nairobi, were 3.5 to 6.0 miles.[9] Automobile ownership encourages the taking of longer trips: the average car trip in Nairobi was almost twice as long as the average foot or bicycle trip.

Per capita ownership of cars in LCDs is still low compared to that in developed countries, but it has grown rapidly. The growing use of private automobiles in LDC cities brings with it a large increase in per capita energy use for transport. If households are at a point where automobile ownership is a possibility, moderate increases in household income may lead to substantial growth in the consumption of transport fuels. The price and availability of automobiles, the ability of people to purchase them, and the existence and adequacy of alternatives to private automobile use, will be major determining factors of energy use in urban passenger transportation.

PLANNED ACTIVITIES FOR FY 1986

During the coming year, we plan to expand our studies to the industrial sector.

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Energy Conservation Measures and Policies for Commercial Buildings for the Association of Southeast Asian Nations (ASEAN)*

M. Levine and I. Turiel

Energy use in commercial buildings is a significant portion of energy demand within the five present ASEAN† member countries. To the extent that expenditures on energy for space conditioning, lighting, and other uses can be reduced without loss of amenity and without compromising the functions which the energy fulfills, the ASEAN nations will benefit economically from measures to conserve energy. These benefits will accrue both to the nations as a whole in the form of reduced oil imports, improved balance of payments, and lower costs in the modern sector as well as to the individual building owners and occupants.

ACCOMPLISHMENTS DURING FY 1985

To assess the impacts of energy conservation in buildings on the economies of the ASEAN member countries, we needed to estimate (1) total energy use of commercial buildings for each country, (2) the cost of the energy used in the commercial sector, and (3) the potential for cost-effective measures to reduce energy use.

Table 1 shows the estimated energy use of the five ASEAN countries for the latest year available, an approximate projection to 1982 to place all on a common basis, the amount of electricity used within commercial buildings, and the total cost of the electrical energy use in buildings. Many of the numbers in Table 1 are estimates, but they are likely to be within 10 or 15 percent of the actual consumption.

The first observation from Table 1 is that buildings consume a significant portion of total electricity in the ASEAN countries. Counting only the electricity for the commercial sector, 26 percent of electricity in ASEAN is used in commercial buildings. If one assumes that about 15 percent of industrial electricity use is space conditioning and lighting industrial buildings, then the estimate of energy use in ASEAN commercial buildings increases to 32 percent of total electricity production. This varies from a high of 50 percent of electricity use for buildings in Singapore to a low of 21 percent of electricity use for buildings in Thailand. These estimates are shown for each of the ASEAN countries in Table 2.

All countries in ASEAN generate almost all of their electricity from oil. If one assumes (for the sake of simplicity) that the cost of a kilowatt hour of electricity is about $0.10 (U.S. currency), then the total annual expenditure for electricity for buildings in ASEAN is between $1.5 and $1.9 billion. (The higher estimate accounts for electricity use in industrial buildings.)

The implications of these estimated expenditures for policies to conserve energy in buildings are sub-

Table 1. Energy use in ASEAN countries.[a]

Country	Energy Use per Capita (1980) (mmBtu/yr)	Total Electricity (1980) (GWh/yr)	Electricity in Commercial Buildings (GWh/yr)
Indonesia	6.8	7,000	2600
Malaysia	21.4	8,470	2510
Philippines	11.3	19,400	4770
Singapore	72.6	6,670	3330
Thailand	11.7	15,900	1800

[a]Sources: Total energy use is derived from "Asian Energy Problems: An Asian Development Bank Survey," Praeger, 1982. The total use includes only commercially sold fuels. Many ASEAN countries use considerable quantities of non-commercial fuels, so comparisons among the countries should be made with care. Population data are from "The World Almanac," Newspaper Enterprise Association, 1984. Total electricity production data and electricity use in commercial buildings are derived from (1) "Energy Planning for Development in Indonesia," Energy/Development International, 1981 and "Renewable Energy Technology and Services—Prospects for a Strong USA/Indonesian Trade Relationship," Jerome Weingart and Associates, 1981; (2) "31st. Annual Report of the National Electricity Board of the States of Malaya;" (3) "Ministry of Energy Report for 1982," Philippines Ministry of Energy; (4) "Energy Conservation in Singapore," Lee Ek Tieng, in Energy—the International Journal, 1983; and (5) "Electric Power in Thailand 1981," Thai National Energy Administration.

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†The Association of Southeast Asian Nations consists of Brunei, Indonesia, Malaysia, the Philippines, Singapore, and Thailand. Brunei was accepted as the sixth member of ASEAN after the bulk of the study was completed. Therefore, it was not possible to include Brunei in this report.

Table 2. Electricity use in ASEAN commercial buildings.

Country	Electricity Use in Commercial Buildings (GWh/yr)[a]	Percentage of Total Electricity Use in Nation	Annual Cost in $ Millions (at $0.10 per kWh)
Indonesia	2600/2700	38.6	270
Malaysia	2510/3070	36.2	307
Philippines	4770/6170	31.8	617
Singapore	3330/3330	50.0	333
Thailand	1800/3350	21.1	335
TOTAL	5,000/18,600	Avg: 32.4	1860

[a]Two figures are presented for electricity use in commercial buildings. The first represents the total use in commercial buildings others than those associated with industrial activities. This number includes the portion of transmission losses in each of the countries appropriately allocated to the commercial sector. The second estimate includes commercial buildings serving the industrial sector. This is derived by assuming that 15 percent of industrial electricity use goes for space conditioning, lighting, and related uses in buildings. The percentage of total electricity use estimates are derived from the latter electricity use (including industrial buildings).

Table 3. Commercial building energy use, trade balance, and oil imports in the three ASEAN countries oil importing countries.[a]

Country	Cost of Oil Imports for Electricity for Commercial Buildings[a] ($ millions)	Balance of Trade Deficit ($millions)	Cost/ Trade Definit
Philippines	340	2800	0.121
Singapore	180	7400	0.024
Thailand	185	2900	0.064

[a]Imported oil is assumed to cost $31/barrel. The source of the balance of trade deficits is "The World Handbook," 1984. The balance of trade deficit data are for 1981.

stantial. If, as we suggest later in this report, ASEAN countries could reduce energy use in buildings by 15 percent in the near term and as much as 40 percent in the longer term, then the total annual reduction in energy costs for ASEAN would be $280 million (near term) and $750 million (longer term). The estimated savings do not take into consideration the growth of the commercial sector. Electricity demand has grown rapidly during the past years among all ASEAN countries and is expected to continue to grow. Electricity use in buildings has also increased, as the ASEAN economies have spurred construction.

It is worth stressing that these reductions in energy costs ($280 to $750 million) are annual savings. Because such a large percentage of electricity is generated from oil, a large portion of the savings will go to reducing imports (with the exception of Indonesia), thus having an impact on balance of payments. Table 3 compares the near-term savings in oil costs to the ASEAN countries that import oil (Philippines, Singapore, and Thailand) with total deficits in trade balance. (A price of imported oil of $31 per barrel is used for the calculation.) It is evident from this table that the 15 percent near-term reduction of energy use by commercial buildings can contribute to a reduction in balance of payments deficits among the three oil importing ASEAN countries.

Thus, a basic conclusion is that energy conservation in ASEAN buildings can make significant contributions to the ASEAN economies.

High Priority Conservation Measures

To gain an overview of the potential for reducing energy use in commercial buildings in ASEAN, it is useful to understand how energy is currently used. This permits the assignment of priorities for revisions to the energy standards.

A hypothetical commercial office building was simulated using the DOE-2 computer code.[1-3] Typical building operating profiles and hourly weather data for Singapore were used in the simulation. Thus, the results are directly applicable to Singapore. However, because the weather in most ASEAN cities is hot and humid most of the year, the results give a qualitative feeling for the sources of commercial building energy use throughout ASEAN.

The total energy use of the hypothetical office building was estimated to be 540 kBtu (158 kWh) per square meter per year; 53 percent of the energy is used for air conditioning (cooling and air movement); 38 percent of the energy is for lighting. The remainder is for miscellaneous equipment.

The largest sources of the cooling loads are solar radiation through windows (28 percent), lights (22 percent), and ventilation (16 percent). Occupants contribute 13 percent of the cooling loads. Walls contribute only 10 percent and glass conductance, 5 percent.

It is useful to look at individual components to understand their contribution to total building energy use. The most important is lighting. As noted, the electricity to operate lights is 38 percent of total energy use. However, lights contribute to the

cooling load as well. When this contribution is accounted for, lights consume 51 percent of the total energy use of the office building.[‡]

Windows are also an important component. Through their impact on cooling loads, they contribute about 13 percent to the total energy use of the building (for a hypothetical building conforming to OTTV requirements). Of equal or greater importance, they have the potential to reduce the amount of artificial lighting required by the building. Thus, windows have a considerably greater potential for reducing energy use than their 13 percent contribution to total energy use suggests.

Of the remaining 36 percent of the energy use of a hypothetical building, the contributions come from miscellaneous equipment (9 percent), ventilation (8 percent), occupants (7 percent), and walls (5 percent).

Because of the variability of miscellaneous equipment, energy savings for equipment have not been analyzed. Ventilation levels are presently set in most codes. The issue of maintaining proper ventilation levels (not too low for health reasons; not too high for energy reasons) is treated as a maintenance problem, discussed below. Loads due to people are not subject to control. Walls contribute little to total building energy use. Because the temperature is above interior comfort conditions day and night for almost the entire year, cooling of the building at night yields little reduction in energy use in Singapore. The potential for designing buildings to take advantage of night cooling in other parts of ASEAN needs to be explored.

Equipment energy efficiency is a final important energy saving measure. Present practice for new buildings in Singapore appears to be good (based on discussions with Singapore professionals). We have no data as yet on building practice in the other ASEAN countries. Equipment in most existing buildings, however, is not adequately maintained: the major concern of building managers is in the comfort of the occupants. Ventilation rates are often higher than necessary. Cooling equipment, fans, and pumps are permitted to degrade in efficiency so long as comfort conditions can be met. Considerable energy savings are likely if policies relating to the maintenance of equipment are adopted and carried out. Policies to establish good maintenance practices in buildings have been given little attention; they deserve much more.

[‡]The assumption is made that the lighting power is 20 watts/square meter. If the actual lighting power is 16 watts/square meter, the total contribution of lighting to energy use (including its effect on cooling) is reduced to 45 percent of the total.

This brief discussion suggests that the following three areas deserve priority attention in considering commercial building energy conservation policies in ASEAN: lighting, windows (especially to encourage the use of daylight), and equipment maintenance. The analysis completed for Singapore suggests a 15 to 20 percent reduction in energy use is cost-effective and possible in the near term and a reduction of up to 40 percent may be possible in the longer term, considering measures affecting lighting, windows, and equipment maintenance. We anticipate that similar magnitudes of savings can occur throughout ASEAN, although the specific measures and the cost-effectiveness is likely to vary with location.

In short, the economic potential of energy conservation in commercial buildings throughout ASEAN is substantial.

Alternative Policy Approaches

There are numerous approaches to realizing the potential for cost-effective conservation in ASEAN commercial buildings. It is premature at this point in the study to provide recommendations regarding the most desirable approaches. However, a description of the alternatives does give a sense of the options available.

The choices range from purely informational to mandatory standards with enforcement. For many countries, it is useful to approach conservation policies in an evolutionary manner, beginning with information and developing over time a set of requirements that can be followed and are accepted without a great deal of difficulty. Thus, we have itemized the policies in different steps, recognizing that different nations have designers and builders who are at different stages of awareness and implementation of energy conservation in buildings. We also recognize that political and economic considerations will play an important role in determining which steps might be omitted, what emphasis to give to different policies, and how far it is reasonable to pursue energy conservation policies for commercial buildings.

Step 1: Modest Information Campaign

This involves making widely available to the building community information packages about the most effective (and presumably most cost-effective) ways of achieving energy conservation in new and existing commercial buildings.

Step 2: Government Buildings Program

The government can set an example by retrofitting existing buildings and requiring new buildings to

be energy conserving. This can take the form of taking measures that will ensure that most government-owned buildings are energy efficient or by choosing a select number of buildings that are made to be very energy efficient.

Step 3: Development of Tools to Evaluate Conservation Measures

A tool is needed for practitioners that is reasonably accurate but relatively simple to use. There are several relatively simple computer codes (running on microcomputers) available in the United States for evaluating commercial building energy use. These tools need to be tested in ASEAN climates against more complex computer tools before they should be made available within ASEAN.

Step 4: Energy Labels

A system that is gaining favorable attention in several countries (notably France and the United States) involves labeling buildings to indicate their expected energy performance. The building labels would provide sufficient information that the owner, occupants, and prospective purchasers could readily determine if the building in energy conserving, average, or the building equivalent of a "gas guzzler." Such labels are presently used for automobiles and most major household appliances in the United States.

Step 5: Component Standards

Many countries throughout the world have adopted the component standards put forward by the American Society of Heating, Refrigeration, and Air Conditioning Engineers (ASHRAE) for various building components (e.g., lighting, wall insulation, heating and cooling equipment). These standards may be optional, mandatory (but without enforcement), or mandatory (with enforcement).

Step 6: Implementation of Mandatory Standards

The choice of methods for the implementation of energy conservation standards in ASEAN (if some member countries choose to adopt standards) is not a simple one. The work accomplished to date—involving considerable quantitative assessment of energy conservation measures in an office building in Singapore—provides new insight into policy approaches. The findings of the analysis suggest that it may be possible to develop relatively simple but accurate equations that will allow (1) a performance approach not suffering from the complexity of previous efforts to permit tradeoffs among all major conservation measures and (2) a microcomputer code that will facilitate the implementation of such an approach. It should be noted that this approach is likely to work in Singapore, where one does not need to be concerned about heating and where the climate is not variable. Whether a simplified but accurate performance approach is possible in other ASEAN climates requires considerable additional research.

Specific Measures to Reduce Commercial Building Energy Use in ASEAN: Lessons from the Singapore Analysis

We list here the most important findings of the analysis of measures to reduce energy use in commercial buildings in Singapore.

- The Desirability of Reducing Lighting Levels
- Daylighting
- Maintenance of Building Equipment
- Alternative Approaches to Implementing Policies to Reduce Energy Use in Commercial Buildings

Conclusions and Recommendations

We have already noted the substantial energy conservation opportunities for commercial buildings in ASEAN. It is worth repeating some earlier figures: ASEAN has the potential of reducing its energy costs by as much as $280 million per year in the near term and $750 million per year in the longer term. These estimates underscore the potential economic benefits of effective energy conservation policies applied to commercial buildings.

Achieving these large energy savings depends on policies adopted by the ASEAN countries. We have made no recommendation on one particular policy approach. Each country should evaluate the different approaches to decide which are most appropriate to their economic and political environment.

PLANNED ACTIVITIES FOR FY 1986

In FY 1986, we intend to extend our analysis of energy conservation in ASEAN buildings, including the following efforts:

- Apply the approach used in Singapore to other ASEAN countries. This involves a comprehensive analysis of impacts of conservation measures in commercial buildings using the DOE-2.1B computer code. It requires the ASEAN participants to gather detailed solar radiation data and participate in the project in other key ways.

- Transfer the DOE-2.1B computer code to those ASEAN countries desirous of using it for the analysis of energy performance of buildings.
- Work with the ASEAN government policy community to understand appropriate energy conservation policy approaches which the technical analysis can support; work with the government, research, and buildings communities to support demonstrations of advanced conservation measures with high potential payoffs within ASEAN.
- Develop a microcomputer program for the implementation of conservation policies, with initial work on this program beginning in Singapore.

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