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Projecting Regional Potentials for Cost-Effective Energy Conservation and Renewable Resource Applications: A Feasibility Study

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I. Introduction

The Natural Resources Defense Council, Inc. (NRDC) has recently completed electrical energy scenarios for California and the Pacific Northwest,*/ using an end-use forecasting methodology. This methodology is relatively well-defined, and can be applied in other U.S. regions, or used to construct a set of projections covering the nation as a whole. One of the major strengths of the end-use method is that conservation options and growth rates of physical capital (housing stocks, etc.) enter into the model explicitly, so that the sensitivity of an energy use forecast to different assumptions can be tested. Scenarios can be computed for high growth and high conservation energy futures, and for various intermediate cases reflecting differential rates of growth and intensities of conservation effort.

This report discusses the feasibility of preparing an instruction manual that would enable a modeler in a particular region to set up a calculational process for predicting energy use, using a format comparable to those of the NRDC scenarios. Such a manual would concern itself primarily with the three energy-consuming sectors most relevant to utilities' demand projections: residential, commercial, and industrial.

The three sections that follow describe the data requirements for each sector and provide some initial guidance

*/ L. King et al., Moving California Toward a Renewable Energy Future: An Alternative Scenario for the Next Fifteen Years (1980); R. Cavanagh et al., Choosing an Electrical Energy Future for the Pacific Northwest -- An Alternative Scenario (1980).

as to how these needs can be filled. Thus, this report can be seen as a preliminary set of instructions to the writer of a comprehensive instruction manual. An actual manual would require more research into potential sources of data, and considerable work on how to translate our general ideas and methodology into specific instructions on what data to seek, where to look for it, and where to enter it into a computational model. A computer program accompanying the manual could provide the calculational apparatus, so the modeler would need to be concerned only with input.

The crux of the end use models for each sector described below is the separate calculation of energy consumed by each end use. After these calculations, energy for all end uses is obtained by summation. Energy consumption by the i^{th} end use E_i (e.g., refrigeration) is the product of the number of energy consuming devices N_i (e.g., the number of refrigerators) and the annual unit energy consumption (UEC) of the device. For a more realistic case, the unit energy consumption is changed over time (t), so there is a different UEC for refrigerators (and other devices) manufactured during different intervals. Energy uses are separated into the sum of products of $N_i(t) \times UEC_i(t)$, the number of units produced at time t times the UEC of those units, summed over all times t.

For forecasting purposes, it is necessary to compute how quickly appliances or buildings are likely to be junked. For example, if $N_i(o)$ refrigerators were built at time o, only $N_i(t)$ will be left after t years. The relation between $N_i(o)$ and $N_i(t)$ can be given in a number of ways, but the simplest is the exponential decay model. If the device "i" has a lifetime L_i, then $(L_i-1)/L_i$ of the original number $N_i(o)$ are in existence one year later (the rest having been junked). After t years, we set $N_i(t)=N_i(o)[(L_i-1)/L_i]^t$. The distribution of new and old units can be obtained by predicting how many old units are still in use at a given time, and subtracting that number from the projected number of total units to obtain the number of new units.

This procedure is followed in all three sectors, as described below. For each sector, data are needed on energy consumption levels as a function of conservation. This information can be used both to compute energy use for an existing or proposed level of conservation and to determine whether or not particular measures are cost effective. For the residential sector, since more data are available, we discuss each end use separately, and address specific opportunities for efficiency improvements that modelers may wish to take into account in projecting future energy needs of particular regions.

II. Residential Sector

A. Electric Space Heat

An end use model attuned to the potential for improvements in space heating efficiency must take account of three types of conservation measures:

(1) tightening the building envelope;

(2) improving the efficiency of the heating system, or substituting more appropriate fuels; and

(3) using renewable resources (through, e.g., passive solar designs).

The effects of each of these measures can be calculated for a prototype house in a given region, using the techniques and assumptions enumerated below.

1. Tightening the Building Envelope

Energy consumption for poorly insulated houses in moderate-to-cold climates can be estimated by the degree-day method (Ref. 1). For tighter houses, a building simulation model is appropriate (commonly used variants are denominated DOE-2, BLAST, NBSLD, TWOZONE). A number of specific assumptions must then be made; the most important involve thermostat levels, infiltration levels,[1/] internal loads, window areas and orientations.

The Lawrence Berkeley Laboratory (LBL) has undertaken extensive calculations of this nature, in support of the federal Building Energy Performance Standards effort.

1/ Infiltration levels are not well known for existing houses, but are probably in the range of 0.5-1.0 air changes per hour, and up to 2 air changes or more for more dilapidated houses. (Grot & Clark, 1979). New houses are in the range of 0.6-0.75 air changes per hour. Other assumptions are described and discussed in Ref. 3, Sec. 4 & Appendix A; and Ref. 4.

LBL's analysis covered single-family detached houses and townhouses for 10 U.S. cities over a range of conservation measures, from uninsulated and medium (0.6 effective air changes per hour) infiltration to R-38 insulation, triple glazing and low (0.3 air changes) infiltration. Floor, wall, and ceiling insulation are included. Results are summarized in Ref. 5, and appear in Ref. 23 in more detailed form.

The same data can be used to describe retrofit cases as well as new construction, since a given R-value of insulation performs the same irrespective of when it was installed. (Of course, retrofit costs are higher.) Extrapolations can be used to estimate the energy use of combinations not explicitly modelled. For example, to find the energy use for a given level of insulation and 1.0 air changes per hour, it is a good approximation to use the results for the same insulation level at 0.6 and 0.3 air changes and to linearly extrapolate loads up to 1.0 air changes.

Cost information for conservation measures can be obtained for new houses (on a national average basis) from Ref. 3, Ch. 4. These figures are unlikely to vary more than ±25% anywhere in the country (Ref. 10).[2/] Installation costs should be obtained locally through a telephone survey of retrofit contractors. Typical retrofit costs in California are

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2/ However, the costs for non-standard sizes of multiple glazing may be several times the estimate of Ref. 3, which is for standard-size windows.

30¢/ft^2 for R-19 ceiling insulation, 60¢/ft^2 for R-11 wall retrofits, and \$3-4/ft^2 for contractor-installed storm windows.

2. Improving the Efficiency of the Heating System

Owners of electrically heated houses can reduce heating costs (improve efficiency) by either switching to gas (or even oil in many cases[3/]), or by substituting a heat pump for resistance heat. Heat pumps generally require central forced-air distribution ducts; however, these ducts will already be present in houses with central air conditioning.

Heat pumps vary in efficiency with model and climate; all models perform more poorly in cold climates. The rated efficiency (COP), which is computed at a relatively warm 47°F outdoor temperature, is generally much higher than the average seasonal COP, which includes the effects of lower efficiency at colder temperatures and reflects the necessity of resistance heat backup.

Oak Ridge National Laboratory has prepared estimates of the seasonal COP for a high-efficiency heat pump, which are listed in Table 4.6 of Ref. 3. They range from 1.38 in Minnesota to 2.02 in California. In comparison, the COP of an electric furnace is 0.9, due to losses (found for both heater types) in the heat distribution system.

3/ \$1.00/gallon oil burned in a new, efficient house (75% seasonal efficiency) is equivalent to 3.2¢/kwh electricity).

Given their efficiency advantages, heat pumps generally have lower life-cycle costs than electric resistance heaters. In warmer climates, where the value of heating energy savings is less, the incremental cost of the heat pump is greatly diminished, since central air conditioning generally would have been used in any event. In colder climates, the dollar savings of heat pumps are sufficiently large to pay for their installation even if most homes lack central cooling systems (Ref. 6).

3. Solar Systems

Passive solar systems are another potentially cost-effective method of saving energy in new buildings. Cost estimation is difficult for a general case, since there may be a number of joint costs. For example, passive storage features such as tile floors or masonry fireplaces may be desirable for decorative as well as thermal reasons. Reorienting windows to the south or adding south windows may also have amenity-increasing aspects.

Even when credit cannot be taken for non-energy-related benefits of passive design features, direct-gain passive houses are generally cost-effective compared with resistance heat (Ref. 7). Energy savings are estimated at 20% or higher, with figures of 60-75% reported by owners of passive houses in sunny climates (Ref. 8). Energy savings will vary widely depending on the habits of the occupants. Greater tolerance to variations in indoor temperature, and particularly to cold morning temperatures, will greatly increase the energy savings possible. More precise estimates of energy use for a given behavior pattern can be determined by using building models such as DOE-2 (version 2.1) or BLAST (version 2.1).

4. Data on Saturations

In most regions of the U.S., saturation of electric heating has been growing rapidly, and saturation of heat pumps in new homes has increased even more rapidly (by a factor of 7 from 1971 to 1978, according to industry sources cited in Ref. 9). Thus, saturations of electric heat in all homes can best be estimated by using a stock/flow model.

Initial saturations can be obtained from the U.S. Census of Housing for 1970. The census form asks what type of fuel is used for heating, so saturations of oil heat, gas heat, and electric heat can be determined. In 1970, in almost every region of the U.S., all electric heat was supplied by resistance heaters. Census data are tabulated by state, county, city and census tract. Utility district data can be built up from state and county data, in most cases.

Electric heat saturations in new housing can frequently be obtained from data gathered by the local utility. Many utilities keep track of the number of new all-electric houses connected each year. These findings can be used in a stock-flow model of electrically-heated houses. Utility saturation surveys are also often available.

Another source of data for cross-checking purposes is the number of new residential building permits issued. For each city or region, the total net number of permits issued (net means permits issued in a given year minus unused permits from previous years) is obtainable; this information often is collected by banks or economic-development agencies. For example, in California, Security Pacific National Bank issues regular reports giving building permit activity by county (Ref. 17), while county-specific data on mobile homes can be obtained from Mobile Home Market Research, Inc. (Ref. 18).

It is generally advisable to assemble as many different sources of data as possible to check for consistency. For example, the number of electrically-heated houses in 1979 could be estimated from a utility survey conducted in 1979 or from 1970 census data coupled with estimates of 1970-79 additions. These numbers should agree. If they do not, there are frequently reasons for adjusting the data to produce a closer accord.

For example, surveys in which the customer tells the interviewer what type of heating fuel he uses are in error in a certain number of cases, because the resident does not know what sort of heat he really has. This is especially true in multi-family buildings with centrally-supplied heat. Utility saturation surveys often elicit non-random responses, with wealthier families more likely to respond than their indigent counterparts, and with foreign-language-speaking families under-represented. This bias may lead to an inflated estimate of the number of new homes, which leads in turn to an inflated estimate of electric heat saturation. Distributions of responses in the survey (e.g., income distribution, single-family houses vs. apartments) should be checked against other sources to test for bias error.

If the responses appear to be biased, then the modeler should construct weighted average saturations by weighting the saturations of electric heat in a given class (e.g., multi-family units or households with $6-10,000 income) by the ratio of households in that class.

Future utility surveys of electric heat can be improved in two general respects. First, questions about heating fuel should list a wide variety of possible answers. Along with "gas" or "electric," respondents should be able to specify "heat pump" or "electric resistance." Also, respondents should be able to answer "not sure" or "other," and should be invited to specify an individual case for "other" (e.g., electric room heaters upstairs and gas furnace downstairs). Follow-up checks, which compare customers' bills with their responses, can help sort out the number of erroneous responses. Such a procedure, when followed by San Diego Gas & Electric, unearthed a significant number of customers who claimed to have electric heating, but whose consumption of electricity declined in winter while their gas bills increased.

Housing removal rate assumptions are needed for a stock/flow model; these can be developed for a given region by using the U.S. Census of Housing's "Components of Inventory Change 1960-1970." Removal rates are typically .010-.014 per year. Data on removal rates for mobile homes are often suspect, as discussed in Ref. 12; in practice, these rates are generally about .03-.04 per year.

5. Modelling Existing Space Heating Energy Consumption

If a variety of insulation levels are found in existing houses, it may not be possible to construct a single "typical" prototype of existing houses. The average amount of energy consumed by one house with 6" of insulation and another without insulation does not approximate the energy use of a house with 3" of insulation.

A few different prototype insulation levels can be established, and saturation levels estimated, by looking at the evolution of construction standards. Houses were typically uninsulated, even in cold areas, before World War II. Insulation levels, and standards, increased thereafter. It appears that prevailing insulation levels correspond roughly with minimum government and industrial standards in effect at the time, even if the standards are not mandatory.

Thus, estimates of insulation levels can be derived from the HUD Minimum Property Standard, or utilities' recommendations for electrically heated houses, which were applicable at the time of construction. Using this procedure to estimate the number of houses at each insulation level for California results in estimates of total space heating energy consumption that are within ±20% of utility sales data (Ref. 11).

B. Electric Water Heat

Conservation measures presently available for electric water heaters include:

1) Reduced shower and faucet water flow;
2) Cold water laundry;
3) More efficient dishwasher and clotheswasher;
4) Tank insulation;
5) More efficient water heaters (replacement);
6) Temperature setback; and
7) Active solar heater.

In addition, heat-pump water heaters recently have become available to consumers.

Accurate data on energy consumption as a function of household water uses are not widely available at present; we suggest below a formula for computing water heater energy use, based on References 12 and 13. We have also derived, from the same sources, a methodology for projecting energy savings potentials.

Electric water heater energy use, in kwh/yr., is given by the equation:

UEC = 935 [standby loss] + (735 [general water use] + 365 x CW [clotheswasher] + 245 x DW [dishwasher]) x PERS,

where UEC = Unit energy consumption (kwh/yr)

CW = 1 if clotheswasher is present; 0 otherwise

DW = 1 if dishwasher is present; 0 otherwise

PERS = number of persons per household

For typical (California, 1975) values of 65% saturation for clotheswashers, 35% saturation for dishwashers, and 2.85 people per household, the equation yields a figure of 4000 kwh/yr.

Conservation measures include:

<u>Low-flow showerheads and faucets</u>: Most conventional showerheads allow about 5-6 gallons/minute (gpm) of flow. Current California standards require showerheads to restrict flows below 2 3/4 gpm, for a reduction of about 50%. Some showerheads can produce a heavy-feeling shower at as little as 1 1/2 gpm. Roughly 2/3 of the general water use, or 500 kwh per person per year, is attributable to showers. Low-flow showerheads should save 1/2-3/4 of this, or 250-370 kwh per person per year. Some of this potential may already have been realized in certain areas; that is, the formula may produce excessive estimates of present hot water heater energy usage.

Reductions in shower flow rates can also be achieved by cheap ($1.00), easily-installed flow restrictors placed upstream from existing showerheads. However, the effect of the restrictor is equivalent to simply turning the faucet to a less open position, so that in many cases a loss of comfort will result, or even a reduction in energy savings if longer showers are needed to rinse fully. In contrast, showerheads designed as low-flow units provide higher-pressure, more comfortable showers at lower water flows.

Faucet flow reductions are also required by California law. Their energy savings are significant in comparison to their low cost, but exact savings have not been quantified. A rough estimate is 10-20% of the water not used for showers, or 3-6% of the 735 kwh of general water use (about 20-40 kwh/yr).

Cold-water laundry: improved cold-water detergents and increased control over clotheswasher cycles (which should use cold water for rinsing irrespective of wash temperature) can reduce clotheswasher energy needs by more than a factor of two. Many loads presently washed hot can be cleaned equally well in cold or warm water. In addition, new washers can reduce overall water usage by about 25%, since present washers range over a ratio of about 2:1 in water consumption.

Reduced water-use dishwashers: Although this area has not been widely studied, some dishwashers use considerably less water than others. The modeler could conduct a survey of water-use ratings (if available) and Federal energy-consumption ratings for locally marketed dishwashers. The results of this survey would indicate the relevant range of water use, and thus the savings potential of reduced water-use appliances.

Moreover, the data could be used directly as a consumer guide.

Higher-efficiency water heaters: The standby loss rate from an electric water heater can be reduced by adding insulation, either at the manufacturing stage or as a retrofit. Retrofit kits cost about $20. Energy savings are about 1/3, or 300 kwh/yr., for both new and retrofit cases. In addition, cost-effective energy savings can be realized by switching fuels to gas or by replacing an electric resistance water heater with a heat pump unit. The estimated COP of heat pumps is 2.5 (Ref. 22), which means that their electricity consumption averages 1/2.5 (40%) that of resistance water heaters. Additional cost is approximately $200-$250 for an 82 gallon (large) unit; savings from installing a heat pump after performing the other conservation measures (all of which are much cheaper) are $35 at 5¢/kwh, so even a large water heater heat pump pays for itself within the life of the unit (about 10 years).

Temperature reduction: Reducing the tank temperature from the typical setting of 150^{o} to 120^{o} can reduce standby losses by about 1/3. In addition, the energy content of hot water consumption by automatically controlled devices (e.g., dishwashers) is reduced. However, storage capacity is also lowered.

For a given level of hot water demand, consumers will usually save more energy by using a smaller water heater that runs hot than by using a larger heater set at lower temperatures. However, if an existing water heater is too large, either due to initial oversizing or to reduced need for hot water due to retrofits, then temperature setback can prove an effective (and free) conservation measure.

Solar-assisted water heat: Solar collectors vary in cost depending on their efficiency and the portion of energy needs provided by the sun. As these two quantities go down, first cost decreases also. For a given electricity price, there is an optimal solar fraction. Current evidence suggests that this optimal fraction is between 1/2 and 3/4.

Saturation data for electric water heaters can be obtained from utility surveys and the U.S. Census of Housing. The user should be sensitive to possible errors in the data, based on residents' inability to distinguish between electric and gas water heat, particularly as regards centrally-heated water in apartments.

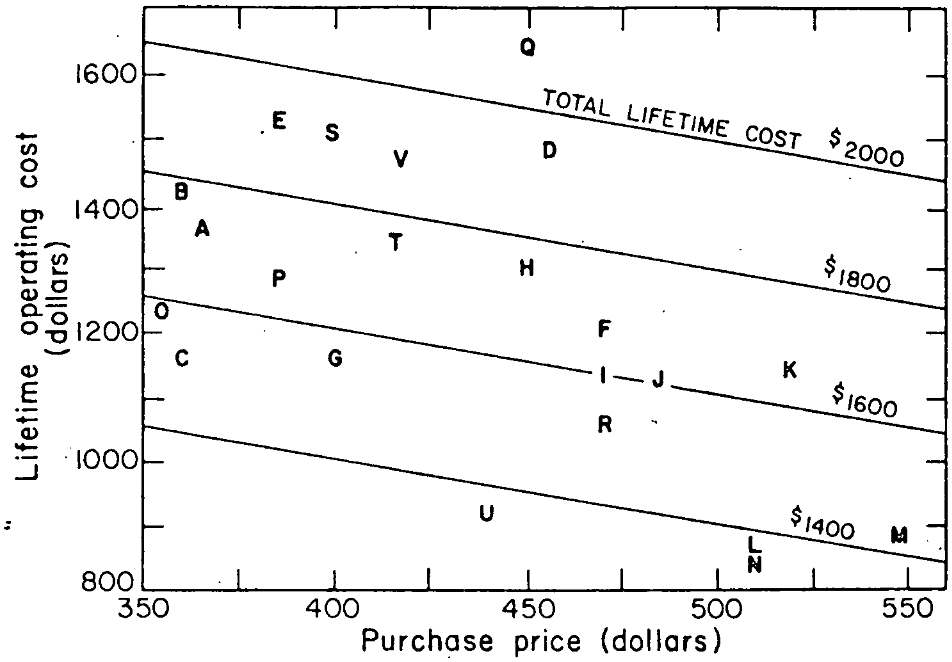
Clotheswasher and dishwasher saturations can also be obtained from utility surveys or the Census of Housing. Additions to the stock since the last census can often be otained from local utilities, which frequently monitor appliance sales. Lacking this data, one can approximate the increase in saturation by assuming that new clotheswashers and dishwashers are added only when new houses are built (that is, by ignoring retrofit additions of these appliances). In San Diego, about 95% of single-family houses and 50% of other units are currently built with clotheswashers; for dishwashers, the percentages are 80 and 60, respectively.

For clotheswashers, an additional accounting problem arises. Saturation surveys generally do not distinguish between a multi-family unit that has its own washer and a unit that shares laundry facilities with the rest of the building. The modeler should set up some consistent assumptions to deal with this problem. One possible assumption is that all units have washers, but that some have hot water use that shows up in the commercial sector (as laundromat energy or apartment common-facility energy). Clearly, other approaches are possible, but the assumptions used should be internally consistent. Future utility surveys will be of greater value on this point if questions are asked that distinguish centrally-supplied water or shared laundry facilities from individually-owned water heaters or clotheswashers.

Reliable data on current levels of water consumption by showerheads, clotheswashers, and dishwashers are not generally available. Federal efficiency labelling should facilitate estimates of averages and variations in efficiency for these appliances. Shower flow rates can be measured for a sample of showerheads in place in homes to determine whether our estimate of 5-6 gallons per minute reflects local conditions (which depend on water pressures and pipe size, along with showerhead design). Replacement "low-flow" showerheads are rated at between 1 1/2 and 3 gallons per minute; these should also be tested *in situ*.

C. Refrigerators

Most conservation measures for refrigerators involve improvements in the component parts of the appliance (*e.g.*, thicker insulation), which can only be performed at the manufacturing stage, and are not realistic retrofit options. However, residential customers do have the choice of purchasing refrigerators of different efficiencies. They also have the option of choosing different feature classes. The four major classes of refrigerators, ranked in order of increasing energy consumption, are: (1) manual defrost (single-door), (2) partial automatic (or cycle defrost), (3) top freezer automatic defrost, and (4) side-by-side automatic. The manual models are typically smallest, and have compact freezer compartments that normally operate at 15^{o} F. Partials combine separate, large freezer compartments that can maintain 0^{o} F with self-defrosting refrigerator compartments. Freezer sections must be manually defrosted two or more times per year. In the frost-free classes, a wide range in capacities and options is available. Variations in efficiency between models of identical size and characteristics are large, often 2:1, so that a very efficient automatic defrost refrigerator may use less energy than an inefficient, smaller, cycle-defrost model. This variation is illustrated in the accompanying Figures from Ref. 16. Energy consumption tests for refrigerators and freezers are performed by the manufacturers: the results will be displayed on labels and are currently available from the California Energy Commission (Ref. 14).



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INITIAL PRICE VS. YEARLY OPERATING COST – REFRIGERATORS
HAVING TOTAL VOLUME OF 15.0 to 18.0 CUBIC FEET

Symbol	Brand	Price	Ref. Vol.	FZ Vol.	Total volume	Energy use (kWh/month)	Annual oper. cost	Lifecycle cost[a]	Defrost[b]
A	Coldspot 7655110	$365	10.92	4.25	15.17	161	$68	$1717	A
B	Coldspot 7657110	360	12.30	4.77	17.07	169	71	1780	A
C	Coldspot 7657010	360	12.40	4.60	17.00	136	57	1502	A
D	Coldspot 7657411	455	12.31	4.75	17.06	175	74	1925	A
E	Coldspot 7657210	385	12.31	4.75	17.06	182	76	1914	A
F	Frigidaire FPS-170TA	470	12.26	4.75	17.01	144	60	1680	A
G	Gen. Electric TBF16VR	400	11.28	4.30	15.58	139	58	1568	A
H	Gen. Electric TBF18ER	450	12.92	4.65	17.57	155	65	1752	A
I	Gibson RT17F3	470	12.40	4.60	17.00	136	57	1612	A
J	Kelvinator TSK170KN	488	12.40	4.60	17.00	136	57	1630	A
K	Kelvinator TSK170KN	520	12.40	4.60	17.00	136	57	1662	A
L	Philco Cold Guard RD16G7	510	11.99	3.62	15.61	103	43	1375	A
M	Philco Cold Guard RD17G8	550	12.37	4.65	17.02	104	44	1424	A
N	Philco Cold Guard RD17G7	510	12.40	4.65	17.05	101	42	1358	A
O	Signature UFO-1525-00	355	10.44	4.74	15.18	146	61	1581	A
P	Signature UFO-1715-20	385	12.28	4.74	17.02	153	64	1670	A
Q	Signature UFO-1625-00	450	10.46	6.05	16.51	196	82	2096	A
R	Westinghouse RT170R	470	12.45	4.65	17.10	127	53	1537	A
S	Whirlpool EAT17NK	400	12.31	4.75	17.06	175	74	1870	A
T	Whirlpool EAT15PK	415	10.86	4.19	15.05	160	67	1759	A
U	Whirlpool EAT171HK	440	12.31	4.75	17.06	110	46	1364	A
V	Whirlpool EAT17PM	$418	12.46	4.75	17.21	175	$74	$1888	A

[a] Lifecycle cost assumes 20 year life. Electricity is assumed to cost 3.5¢/kWh, and fuel inflation rate (in true dollars) cancels interest rate.

[b] A = Automatic defrost, refrigerator and freezer.

Fig. 1. Operating cost vs purchase price in 1976 for 21 automatic defrost refrigerator-freezers in the size range of 15 to 18 ft^3 for refrigerator plus freezer. Operation cost is calculated as kWh/month (from the 1974 AHAM Directory[4]) x 3.5¢/kWh (1976 electric cost) x 20 years.[5] Purchase price established by telephone survey; three stores in San Francisco Bay Area for each model.

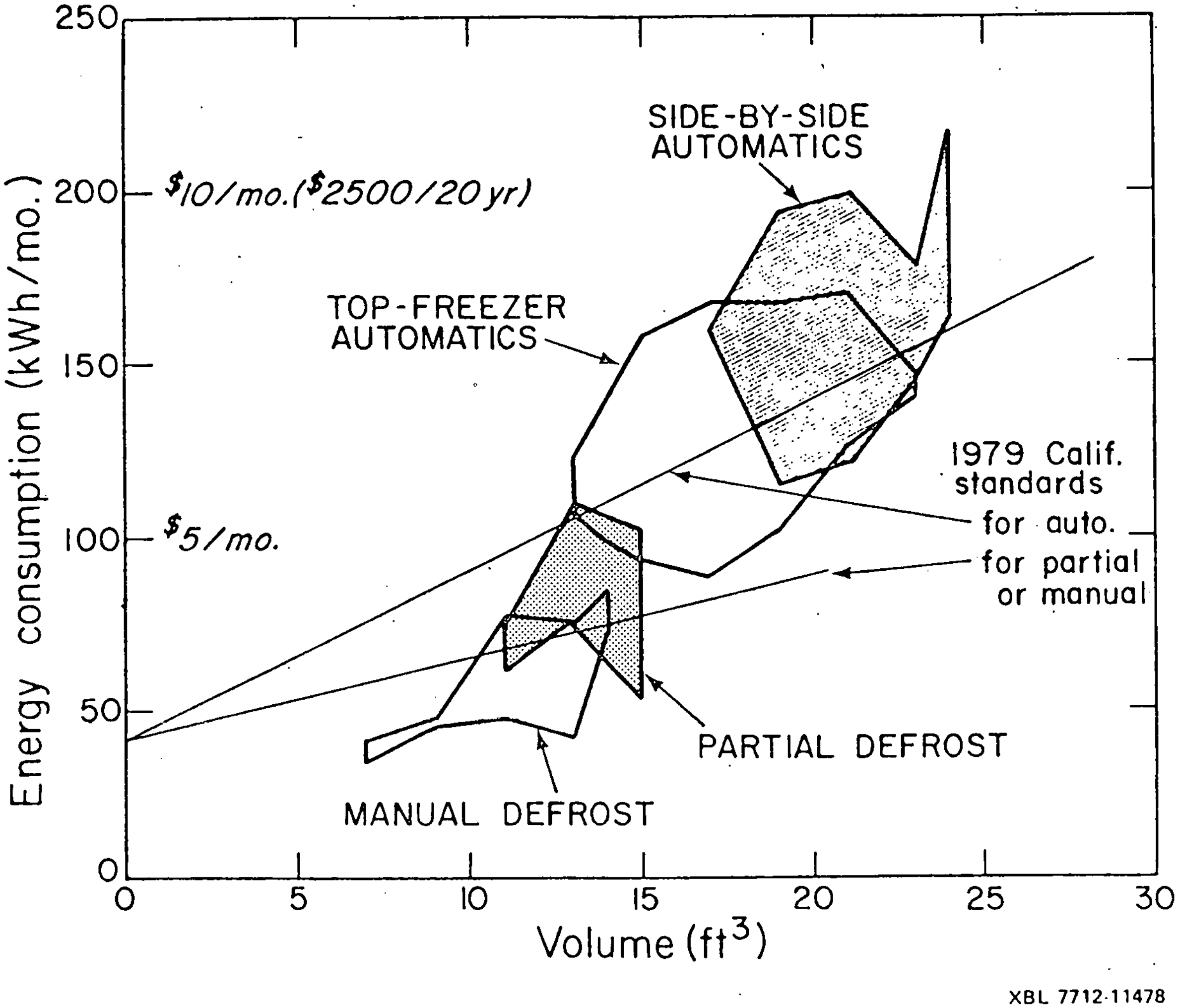

Fig. 2. Refrigerator-freezers, 1977. Range of energy usage as a function of size and feature class. Refrigerators are grouped in bins of 2 ft^3, thus the point at 11 ft^3 represents units with size between 10.0 and 11.9 ft^3 inclusive. For units with a mullion heater switch the average of energy use with switch on and off is used (from Ref. 4).

Estimates of current refrigerator energy use can be made by using industrial data keyed to size and class. Averaging over all models, the typical refrigerator now in use requires 1200 kwh/yr, but the average for new machines is about 1600 kwh/yr (Ref. 12). Within a given feature class, energy use is relatively independent of size. Current sales volume and energy consumption averages by class are as follows:

	Manual	Partial	Top Freezer Automatic	Side-by-Side Automatic
Sales (%)	12	17	49	22
kwh/yr	700	1250	1800	2050

Some manufacturers are working on designs which substantially exceed the best efficiencies now available. A consultant study recently concluded that cost-effective changes in refrigerator design could reduce energy consumption in the top-freezer automatic class to 50-55 kwh/month, 40% better than the best performing model presently on the market (Ref. 15). Since the publication of that study, several prototypes have been built, both by major manufacturers and by backyard inventors, which achieve this magnitude of savings. Thus, more efficient models may become available in the future.

Ultimate energy savings will depend on the mix between classes of refrigerator and on the market penetration of the more efficient types. Federal or state standards may hasten this trend; for example, consider the average energy use of refrigerators complying with the current California standard:

	Manual	Partial	Top Freezer Automatic	Side-by-Side Automatic
kwh/yr	650	850	1350	1600

Saturation of refrigerators is presently about 115% (Ref. 12); that is, almost all households have one refrigerator and a significant number have two or three. A properly designed survey form would therefore ask for the type (class) of each refrigerator in use. If no survey data are available, the mix of refrigerator types in use can be generated from stock-flow models, as explained in Ref. 12.

D. Freezers

Conservation measures for freezers, like those for refrigerators, are largely limited to replacement of existing stock with more efficient models. There is presently less variation in efficiency among models for freezers than refrigerators, although this may change as manufacturers respond to growing demand for high-efficiency freezers.

There are three classes of freezers: chest, upright manual defrost, and upright automatic defrost. Approximate energy consumption, in kwh/yr, for different classes and sizes of freezers are given in the table below, taken from Ref. 12. The table also lists the average energy use of models that comply with the current California standard.

	Chest		Upright Manual		Frost-Free
	small	large	small	large	
Present Energy Use	850	1450	975	1775	1875
California Standards	790	1300	875	1125	1550

Saturations of freezers vary from place to place, as does the model mix. The Association of Home Appliance Manufacturers collects data on the number of freezers in each class shipped to each state; this information, along with census or utility survey data, should allow the modeler to estimate saturation of freezers by type.

As is the case with refrigerators, poorly designed utility surveys on freezers often elicit vague answers. An unambiguous question is: "What type of freezer (if any) do you own?" Possible answers should be "chest, upright manual defrost, upright automatic defrost, upright, unsure, other." Space for several answers should be provided, in case some respondents have more than one freezer.

Efforts to project future end use needs for freezers should not neglect the possibility that, in the near future, manufacturers will introduce freezers that are much more efficient than current models.

E. Air-Conditioning

Conservation measures for air-conditioning energy use fall into several categories:

1) Alteration of the building envelope to reduce heat gain through
   a) insulation, or
   b) shading of windows;
2) Reductions in internal heat generation (*e.g.*, appliances, lights);
3) Improvements in equipment efficiency ("EER") or, in dry climates, use of evaporative coolers; and
4) Changes in comfort or management (use of natural ventilation when possible, use of higher thermostat settings, pre-cooling the house during the night with fresh air).

For poorly insulated buildings, insulating walls and ceilings can save substantial fractions of cooling energy, as shown in Refs. 3, 5, and 12. However, once levels of about

R-11 are realized, additional insulation has relatively little effect on cooling load, except in the very hottest climates (e.g., southern Arizona). For an insulated house, almost all of the cooling load is attributable to heat gain from the sun and from internal sources. Reduction of these two forms of heat gain constitute, therefore, the most effective conservation measures after the house has been insulated. Data on cooling loads as a function of insulation can be obtained from Refs. 3, 5, and 23.

Shading can be accomplished through the use of permanent reflective glass or reflective film on east and west orientations (but treating south windows generally costs more in increased winter heating than it saves in cooling, unless the treatment can be removed in the winter), and by installing white interior window shades or blinds, exterior roller shades, permanent exterior overhangs, trees, or awnings. Precise savings have not been quantified.

Reductions in internal energy loads are desirable for their direct savings, but for insulated houses they can have a large effect on cooling needs as well. The effects of doubling or halving internal loads are shown for three cities in the sensitivity analysis in Ref. 3, Appendix A; they can be calculated for other places using building models.

It should be noted that the data from Refs. 3 and 5 were obtained by assuming a rated "EER" of 8.0. Typical EER's of existing equipment are around 6.5, while the range of available efficiencies is large, as shown in Figure 3 from Ref. 16. Energy use is inversely proportional to EER, so an air conditioner with an EER of 6.5 would require 8/6.5 or 1.23 times as much energy as those listed in Refs. 3 and 5. Data from manufacturers, obtained in 1976, shows that increasing the efficiency of a central air-conditioner costs $0.24 per watt of rated power saved (Ref. 19). Even larger savings can be realized by increasing EERs of room air-conditioners, since the upper range of EERs in room units currently exceeds 12. Room air-conditioners of high efficiency cost about $0.18 extra per watt saved in 1976 (Ref. 19).

Saturations for central air-conditioning can be computed through methods similar to those appropriate for electric heat or for other appliances. Room air-conditioning saturations are more difficult to obtain accurately, because of sloppy accounting as respects owners who have two or more air-conditioners. Future surveys should attempt to determine how many air conditioners of each type are being used by each household.

Energy consumption by room air-conditioners can be determined by multiplying wattage ((capacity in Btu/hr)/EER) by number of hours of usage per year. Wattage is fairly easy to determine, since average capacities are about 10,000 Btu/hr (Ref. 12). Hours of usage should be determined locally; they

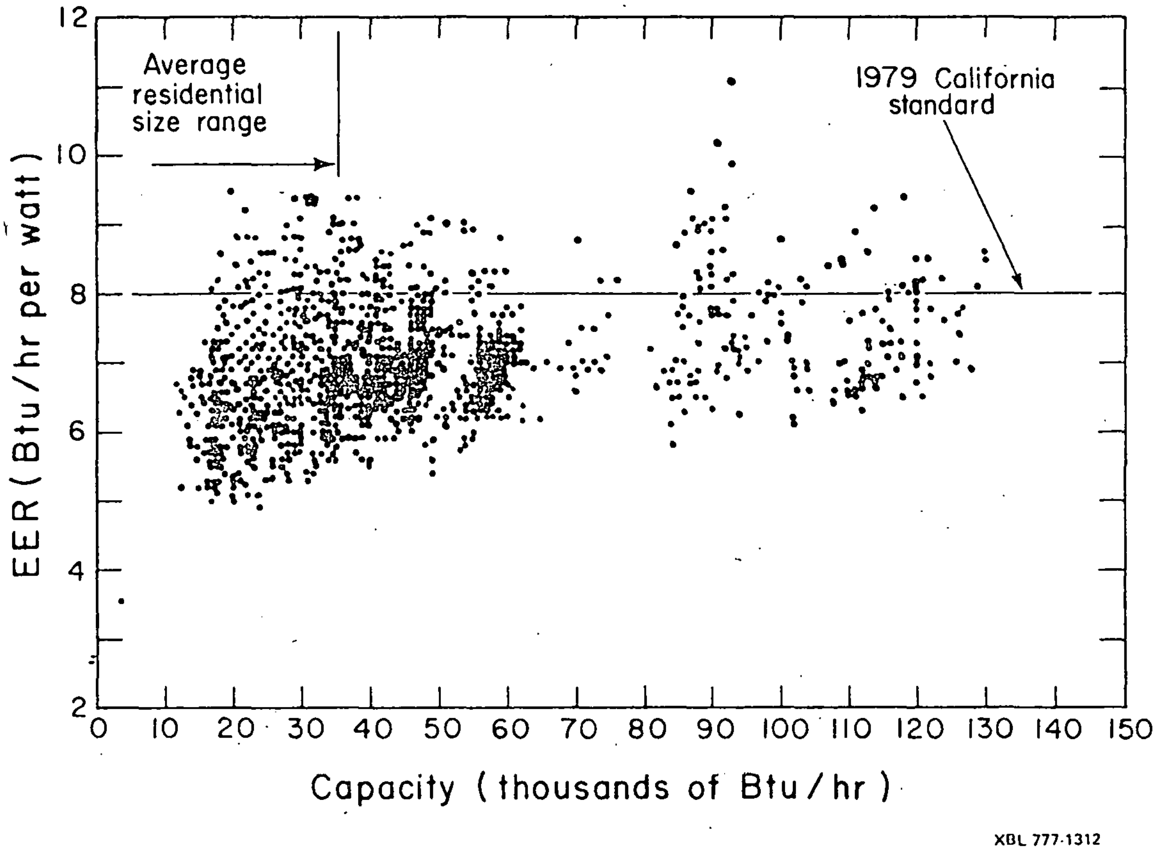

Fig. 3. Split-system central air conditioners. Scatterplot of efficiency vs size (from Ref. 3). See Table 2 for California efficiency standards.

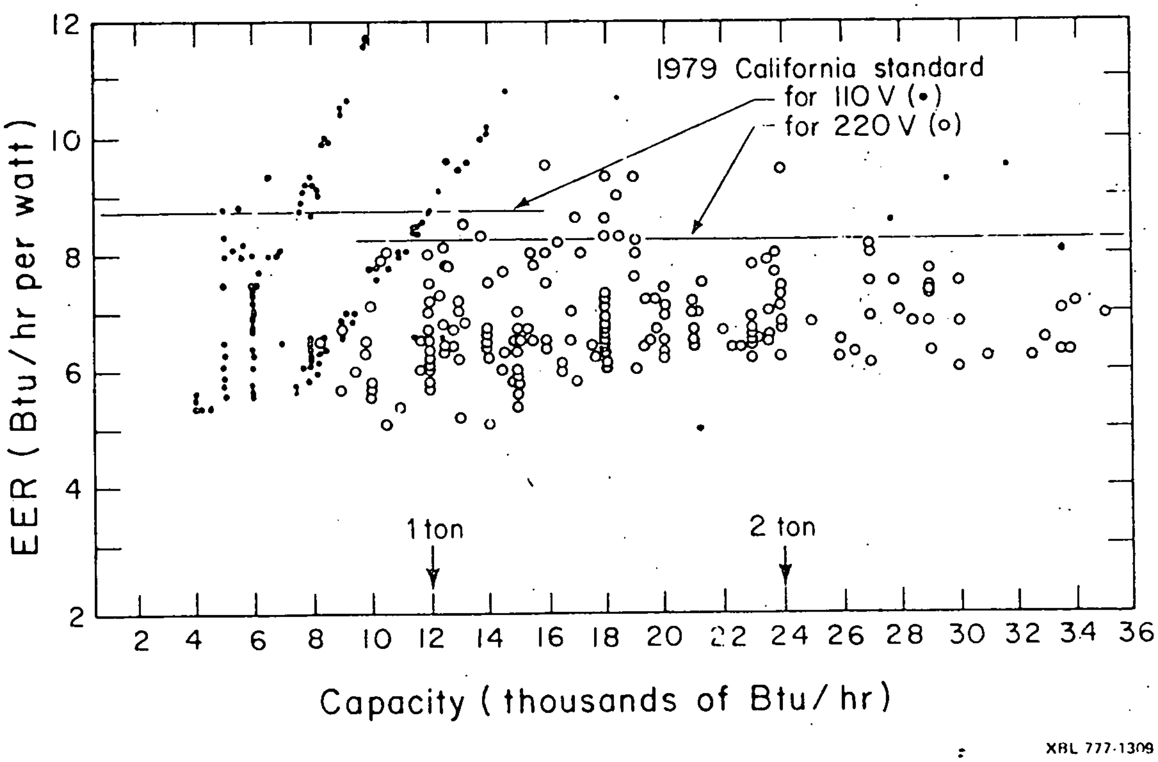

Fig. 4. Window mounted air conditioners. Scatterplot of efficiency vs size

are estimated at about 300 hours in New York/New Jersey and 600 hours in California (Ref. 12).

F. Lighting

Lighting energy use in residences has been fairly stable over the last 25 years, with gradual increases until 1973 and apparent gradual decreases since then. Lighting levels in residences are much lower than in commercial buildings, so delamping in residences may not be a generally applicable procedure.

Conservation measures will generally involve the use of more efficient lights, or occasionally the use of task lighting. A number of high-efficiency light sources are available now (or will exist by 1982) that provide color rendition similar to that of incandescents. These include warm white fluorescents and proposed special light bulbs. Both sources use about 1/3 the amount of energy for the same illumination as incandescents. (Since some of the energy use in fluorescents is for the ballasts, the rated wattage will be 1/4 that of a comparable incandescent.)

Replacing incandescent fixtures with high-efficiency fixtures of equal light output will be cost-effective whenever the fixture to be replaced is used more than about 500-1000 hours/year. The main obstacles to such measures have been the related issues of equipment availability and aesthetics -- few attractive fluorescent fixtures are currently on the market.

Since a disproportionate share of lighting energy is consumed by relatively few high-use fixtures, targeted retrofit installations of high-efficiency fixtures may save a substantial portion of total energy use. For example, if 3/4 of lighting energy is burned in fixtures with heavy enough use to justify retrofit, 2/3 of the 3/4 can be saved (i.e., half of the original lighting energy use). Average per-household usage in 1975 was about 1150 kwh/yr (Ref. 12).

Two issues must be noted regarding lighting and conservation. First, fluorescents have not been widely promoted or employed as an energy conservation technique. Most fluorescent lighting in houses has been used to increase lighting levels rather than to save energy. Energy-saving fluorescents should be designed for areas (e.g., dining rooms, living rooms) where relative low light levels are required, keeping in mind consumers' preference for attractive fixtures. Second, some commentators have raised the issue of possible adverse health effects from fluorescent light, invoking the work of John Ott. Ott's hypothesis is that artificial light lacks allegedly healthful ultraviolet (UV) frequencies (Ref. 20). But, as Ott himself acknowledges, incandescent lamps have even less UV than fluorescents. More research is needed on the validity of the link between UV and health, but there is no reason to prefer incandescents over fluorescents on the basis of this theory.

Fluorescent lights are presently available in three forms: replacement fixtures using straight lamps (like those used in offices), replacement fixtures using circular lamps, and screw-in light bulb replacements using circular lamps. Imminent innovations include high-frequency ballasts, which will save 20% or more of fluorescent lighting energy while eliminating flicker and hum. These ballasts, which should be commercially available by 1981, also allow dimming.

G. Cooking

Past load studies have estimated that about 1200 kwh/yr are used for cooking. No significant conservation measures for electric ranges or ovens have been proposed until recently; the advent of microwave ovens and convective ovens complicates the overall picture. Federal test procedures for ranges/ovens (Ref. 21) have created uncertainty about whether microwave ovens save a significant amount of energy compared to conventional cooking. Tests by Pacific Gas and Electric have also produced mixed results. Microwaves save energy compared to both surface burners and conventional ovens on some tasks, fall between burners and ovens on others, and fall below all alternatives for still others.

Energy can be saved in cooking by using gas rather than electricity (particularly for surface burners), by using surface units rather than ovens, by covering pots and simmering more slowly, etc. Savings from such lifestyle changes have not been carefully studied. Future innovations are likely to involve better-insulated ovens and reflective oven walls; such expedients may reduce oven energy needs by up to half.

H. Dryers/Washers and Dishwashers

No significant conservation measures for clothes dryers are presently available. The only ways to save energy in this subsector are to refrain from using dryers (*e.g.*, by using clotheslines instead), or to substitute gas-fired dryers.

Electric dryers currently use about 950 kwh/yr for a family of 3.1. Usage is proportional to family size (Ref. 12). Saturations can be estimated from census and survey data, subject to the problems created by loose definitions of ownership in multi-family buildings.

Washers use only a trivial amount of electricity directly -- about 70 kwh/yr. Their only significant effect on electricity demand results from their hot water consumption, if the water is heated directly. See the discussion earlier under "water heaters".

Dishwasher electricity use is also small -- 250 kwh/yr (Ref. 12). Power drying options may increase this figure by about 100 kwh/yr. But, again, the energy impact of dishwashers is primarily a function of hot water consumption.

I. Televisions

Over the last 15 years, significant efficiencies have been introduced in the design of TV receivers. In 1965, an average color TV used 300 watts, while a black-and-white TV used 175. By 1977, data collected by the California Energy Commission (CEC) showed that these power requirements had dropped to 120 w for color and 44 w for black-and-white. Comparison shopping readily demonstrates a potential for still further improvement; it is easy to find television sets which use less power than the best that were incorporated in the CEC data base.

Despite the steady trend of efficiency improvements, there remains a considerable range of efficiencies available to the contemporary consumer. As is the case for air-conditioners and refrigerators, further conservation could be achieved through selective shopping. However, the incentives for such discrimination are insubstantial, since overall TV energy consumption is relatively low. Energy consumption for an average household (virtually all households have at least one television) is given by the product of average wattage and annual usage. Surveys in California show 1900 set-hours of use per household per year, on the average; this figure can be used as an approximation if local surveys are unavailable.

J. Miscellaneous small appliances

Energy consumption trends in small appliances represent a tradeoff between two conflicting phenomena: increases in the number and ownership of small appliances and efficiency improvements in the design and use of such appliances. For example, over the last ten years, several new appliances have appeared (e.g., waterbed heaters), while others have increased markedly in numbers (e.g., electric hair dryers). But audio equipment has become much less energy-intensive, and equipment like electric irons has been used less frequently as a consequence of technological changes (e.g., permanent-press fabrics). Also, some apparent proliferation in appliance ownership (e.g., crockpots, small cookers) has not resulted in more energy use, but merely a diversion of energy use from one appliance to another.

The net effect of these changes is not known, but it is probably small. A trend of constant energy use for miscellaneous appliances is the most reasonable guess for a projection, unless regional or local conditions render one appliance or appliance-type so prevalent and important that product-specific conservation measures can have an appreciable impact.

References: Residential Sector

(1) ASHRAE, "Handbook of Fundamentals," 1977.

(2) R. A. Grot and R. E. Clark, "Air Leakage Characteristics of Low-Income Housing and the Effectiveness of Weatherization Techniques for Reducing Air Infiltration," presented at the ASHRAE/DOE Conference on the Thermal Performance of the Exterior Envelopes of Buildings, Dec. 3-5, 1979, Orlando, Florida.

(3) "Economic Analysis of Proposed Building Energy Performance Standards," Pacific Northwest Laboratory, PNL-3044, 1979.

(4) D. B. Goldstein, M. D. Levine, and J. Mass, "Methodology and Assumptions for the Evaluation of Building Energy Performance Standards for Residences," Lawrence Berkeley Laboratory, LBL-9110.

(5) M. D. Levine, et al., "Evaluation of Residential Building Energy Performance Standards," presented at the ASHRAE/DOE Conference on the Thermal Performance of the Exterior Envelopes of Buildings, Dec. 3-5, 1979, Orlando, Florida.

(6) D. B. Goldstein, "Memo to Clark Bullard on Heat Pump Cost Effectiveness and Energy Budgets, 24 August 1979," in DOE Technical Support Documents of Building Energy Performance Standards, Notice of Proposed Rulemaking, DOE/CS/0112.

(7) Booz, Allen, and Hamilton, "'BEPS' Renewable Resource Analysis," prepared for U.S. Department of Energy, 1979.

(8) W. A. Shurcliff, "Solar Heated Buildings: A Brief Survey" (Shurcliff, Cambridge, Mass., 1976).

(9) E. Hirst, "Understanding Residential/Commercial Energy Conservation: The Need for Data," Minnesota Energy Agency, St. Paul, Minn., 1979.

(10) See local cost indices for conservation jobs (insulation, glazing) compiled by R. S. Means, "Building Construction Cost Data 1979," (R. S. Means, Inc., Doxbury, Mass.).

(11) S. M. Berman, et al., "Preliminary Report on the Assessment of Energy Conservation Strategies and Measures," Lawrence Berkeley Laboratory report to the California Energy Commission, 1976.

(12) S. M. Berman, et al., "Electrical Energy in California: Data Collection and Analysis," Lawrence Berkeley Laboratory, UCID 3847, 1976.

(13) R. Clear, "Water Heaters," Lawrence Berkeley Laboratory, 1975 (unpublished).

(14) "Directory of Refrigerators and Freezers certified to comply with the requirements of California Appliance Efficiency Standards as of March 2, 1979", reproduced by Pacific Gas & Electric Co., San Francisco.

(15) "Study of Energy-Saving Options for Refrigerators and Water Heaters: Volume 1: Refrigerators," Arthur D. Little, Inc., Cambridge, Mass., 1977.

(16) D. B. Goldstein and A. H. Rosenfeld, "Energy Conservation in Home Appliances Through Comparison Shopping," Lawrence Berkeley Laboratory, LBL-5910, 1978.

(17) Research Department, Security Pacific National Bank, "California Construction Trends," Los Angeles, California.

(18) "California Mobile Home Report, Annual Summary of Sales: A Special Summary and Analysis of Retail Mobile Home Sales in California," Mobile Home Market Research, Inc., Woodland Hills, California.

(19) A. H. Rosenfeld, "Some Potentials for Energy and Peak Savings in California" in Energy Use Management, Proceedings of the International Conference (New York: Pergamon Press, 1977).

(20) J. Ott, Light and Health.

(21) Federal Register, 10 May 1978, Part II, 43, page 20116.

(22) E. F. Gorzelnick, "Heat Pump Water Heater Makes Debut," Electrical World, 15 April 1979.

(23) M. Levine, D. Goldstein and J. Mass, "Residential Building Energy Performance Standards, Series V Results," Lawrence Berkeley Laboratory, Feb. 7, 1980.

III. Commercial Sector

Commercial buildings are a vexingly elusive target for end use analysts. Empirical information is relatively scarce, in comparison with the residential sector, and available data are in many cases self-contradictory. In principle, the commercial sector can be modelled like the residential sector on an end-use basis, for existing (or retrofit) stock and for new additions. The form of such an "ideal" model is described below. In practice, however, it will probably be necessary to use sector-average estimates of unit energy consumption per square foot (UEC's), and even then aggregate figures will be difficult to establish convincingly.

A comprehensive model of the commercial sector would attempt to disaggregate energy use into end uses for each major building type. The primary end uses are heating, cooling, ventilation (often considered part of the heating or cooling load), lighting, water heating, and cooking. The latter two end uses generally make trivial contributions to overall energy demand, except in a few types of buildings (e.g., restaurants, gymnasia, hospitals).

Buildings can be categorized in a number of ways, depending on the amount of detail needed and the data sources used. A common classification scheme, which uses only a few categories to cover most of the building stock, is Offices, Stores, Schools/Colleges, Hotels/Motels, and Other. "Other" includes public buildings (e.g., churches), warehouses, service stations, and other less inclusive categories.

This system has manifest imperfections. For example, government buildings may be office-like, or may be more closely akin to schools than to most structures in the "Other" category. Department of Defense structures may be omitted and are hard to classify. It may be misleading to merge shopping centers with other "stores," despite possibly significant differences in energy characteristics.

The scheme described above sets up six end-use categories for five types of buildings, so thirty UEC's are needed. However, direct quantification of most of these is impossible. We are aware of no studies which measure energy consumption by end use for any type of commercial building. There are a few studies that measure overall UEC's for buildings, but the allocations by end-use are derived from simulation model results. This methodology is reasonable, in principle, but it is troublesome in practice because there is no record of consistent agreement between overall UEC's predicted by models and actual measurements.

Thus, it probably makes most sense to construct aggregate sector-wide UEC's which are broken down by end use to the extent possible. When this procedure has been used in the past, it has generally been based on office prototypes. (Refs. 1,2) Three or four UEC estimates will be needed for the energy modelling: UEC's for existing stock and for retrofits of this stock, possibly UEC's for recent or near-future conditions, and UEC's for future conservation-standard cases. In addition, estimates of present and future building stocks (in ft^2) will be needed. Derivations of the relevant numbers are discussed below.

A relatively straightforward procedure for estimating building stocks is described in Ref. 1. It basically draws on the use of building construction data (e.g., Ref. 4) and a model of building replacement.

Building construction data are usually available going back to about 1920. The stock of post-1920 buildings can be computed by calculating the number of square feet remaining from each vintage of construction and adding the results. The method of Ref. 1 is to use the following decay curve:

$$B(\Delta t) = \{1 - 1/(1+\exp(6.91 - 0.1536\Delta t))\}B_0$$

where $B(\Delta t)$ is the number of buildings still in use t years after construction and B is the number of buildings added in a year. This curve is consistent with a mean building life of 45 years.

An alternate formulation is an exponential decay model similar to that used in the residential sector: $B(\Delta t) = B_0\{\frac{L - 1}{L}\}^{\Delta t}$ where L is the mean life of a building (45 or 50 years). A disadvantage of the exponential formulation is its implicit assumption that a building has the same probability of being demolished in its first year of operation and its 60th, which is intuitively implausible. On the other hand, the exponential model predicts that there are still a significant number of 100-year old buildings left, which seems reasonable, while the Jackson model (Ref. 1) predicts that almost none (less than .025 percent) are still in existence. In addition, the exponential model permits simpler computations.

The procedure outlined above yields the stock of existing buildings that were erected at a time when reliable construction records were generally maintained. Several methods can be used to estimate the number of buildings remaining from earlier periods. For example, the modeler can "back-cast" construction data by extending recorded trends indefinitely into the past. Alternatively, ratios of commercial floorspace to other values (e.g., number of service employment jobs) can be determined; if those other data are available for the era prior to compilation of construction records, they will afford a means of estimating construction trends during that period.

In practice, more than one method should be used, and the results should be checked for consistency. Errors introduced by inaccurate estimates of the initial building stock have a relatively small effect on tabulations of existing stock, given the decay rate of older buildings. It should be noted that the widely accepted estimate of a 45-50 year life for commercial buildings is not well documented, which injects some uncertainty into building stock estimates.

Future building stock is usually estimated by reference to economic growth projections. Commercial building floor space (except schools) is assumed to grow in proportion to commercial sector employment, or, in less sophisticated models, in proportion to GNP.

Energy use per square foot of existing stock can be derived from data on energy sales and building stock. Estimates of total energy sales (gas, oil and electricity) to buildings are divided by total square footage to estimate UEC's. Isolating sales to commercial buildings can be difficult, because utilities often classify customers solely by relative magnitude of consumption, using three categories: "residential," "small light and power," and "large light and power." While these categories are often interpreted as residential, commercial and industrial, some effort should be made to test this assumption. "Small light and power" may include light industrial customers or residential apartment buildings with master meters. Some large commercial projects may be billed under "large light and power."

Energy consumption in the aftermath of retrofits can be predicted in one of two ways. Percentage savings off the existing base can be estimated based on past experiences or on judgments about how many of the well-understood retrofits (see Refs. 5 and 6) are appropriate. Lighting energy savings can be projected by assuming a delamping rate (e.g., 1 watt/ft^2 removed) times the number of annual operating hours (3300 for an average building test cycle in the California Energy Commission's evaluation technique for performance standards, or 3000 as an industry rule of thumb). These figures could prove conservative, since many buildings are undoubtedly illuminated for more than 3000-3300 hours per year.

Deriving UEC's for new construction requires the use of simulation models. This procedure introduces problems when the models are not "normalized" to project existing energy use accurately. This non-normalization may reflect model error, but is more likely traceable to inaccuracies in specifying the characteristics of the building being modelled.

Unfortunately, there is no convincing "theory vs. reality" test. All we have are comparisons between models of a prototype building or a few sample buildings under assumed operating schedules, compared to metered data for all existing buildings (which operate on unknown schedules).

Several sources are available for projecting future UEC's. The American Institute of Architects/Research Corporation study that led to DOE's performance standards for commercial buildings has produced considerable data (Refs. 7,8), reflecting simulation model runs on designs of buildings "as built" in 1975 and as redesigned. The proposed performance standards are based on the redesigns. More data from follow-up work are anticipated shortly.

These results appear to underestimate present energy use by about a factor of two, compared to an Oak Ridge model (see Ref. 1). However, comparison of the Oak Ridge model input data to the few studies of actual energy use in commercial buildings (Ref. 9) show that the Oak Ridge estimates are probably too high. (See also Ref. 10).

Given this clash of authorities, two alternate approaches are possible. The first is to investigate actual building performance in the area under study, for buildings constructed in 1975, and to compare the results to the AIA/RC projections. The ratio of actual energy use to design energy use can be used to adjust the performance-standard energy use estimates. This approach was used in calculating the economic impact of the federal performance standards for DOE. (Ref. 11). Alternatively, one can assume that the model results represent actual expected values for UEC's under the more careful building maintenance and energy management that can be anticipated in the future.

Clearly, research performed under local conditions would greatly increase the accuracy of commercial energy projections. Surveys to establish actual energy use per square foot can be used for comparison with the UEC's obtained by calculating the ratio of overall energy consumption recorded by utilities to overall commercial floor space. Surveys to establish the types of HVAC systems in use, operating schedules, lighting levels, and lighting schedules can be used to generate one or more local prototype buildings. Simulation results from a building model such as DOE-2 (Ref. 12) can be used to try to duplicate existing data on energy consumption and then to model the impact of new conservation initiatives.

The preceding discussion has emphasized the data problems afflicting this area. An obvious question is why the commercial sector is so much more difficult to handle than the residential sector. A partial answer includes the following elements:

1) No federal data surveys: For the residential sector, researchers have access to the Census of Housing, which measures a number of useful energy-related properties, such as penetration of air conditioning, space and water heating fuels, and appliances. The census reports encompass all housing everywhere in the U.S. For commercial buildings, there is no comparable source of information permitting even a threshold estimate of the total number of structures.

2) No information on the range of energy consumption as a function of building size: For residences, average energy use can be estimated by looking at average gas or electric bills to customers. Since most houses are in the same size range (1200-2400 ft^2), average bills afford a check on the validity

of estimates of typical energy use that are based on total sector use divided by total number of customers. But for commercial buildings, we have no data on individual customers' bills as a function of floor space, so there is no easy way to confirm the reasonableness of sector-average UEC's per square foot.

3) More intransigent survey biases: Most residential and commercial energy studies are tainted by a "me-and-my friends" bias; that is, they tend to select samples of buildings, chosen for convenience, which resemble the researchers' homes and offices. For residences, this means that surveys tend to study upper-middle class suburban households with middle-aged adults and school-aged children, at the expense of single-parent households or older adults or poor families. However, it is often possible to compensate for these biases, by expressing the results as functions of explanatory variables, such as family size, house size, appliance ownership, etc. When average values of the explanatory variables are substituted for the values produced by the survey, more accurate characterizations of residential end uses become possible.

For commercial buildings, available studies tend to feature professionally managed, class A offices, large contractor-built stores, and the like. Neighborhood stores, small motels, small office buildings, and owner-occupied structures are often ignored. Unfortunately, it is harder to establish quantitatively how much the surveys distort reality, both because the key variables (analogous to income or household size for residences) have not been identified and because sector averages for potentially relevant variables are not known.

Unsurprisingly, then, commercial sector energy use has proved more difficult to model than its residential counterpart. That is, when residential appliance saturations are multiplied by UEC's determined from engineering calculations or surveys, the results are generally within ±10% of residential electric bills. If the same procedure is followed for residential gas customers, using assumptions about the stock of insulation in homes (which is not very well known), actual gas bills can be predicted to within ±25%. But models of commercial sector energy use, particularly fuel use, often disagree by a factor of 2. Such discrepancies are probably attributable to insufficient data on building equipment and operating schedules, and on the stock of buildings.

The data problems described here can often be resolved locally through surveys. A few such studies are presently being performed by the Department of Energy. Greater exchange of information should allow survey-takers and survey designers to profit from the wisdom and mistakes of their predecessors.

Close contact between energy modelers and survey designers is also important. Most surveys are wearisomely long and ask questions that do not lead to any inputs for either building thermal models or energy projection models. Yet important questions are frequently omitted.

Spot checks should be made to confirm the responses reported in surveys. Does the building engineer's estimate of lighting levels correspond to a real measurement, or to his intuition? Does the connected load or peak load accord with the sum of equipment and lighting peaks? Are the lights really out at midnight as claimed?

The construction of a commercial end-use analysis will require creative use of limited data. Therefore, an instruction manual for this sector will present special difficulties, because the author cannot set out cookbook formulas for being creative. On the other hand, even a set of instructions that leads to a "wrong" answer will be of some value. It will provide some basis, other than pure guesswork, for estimating conservation potentials, and it may elicit constructive suggestions for collecting better or more explicit information.