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IMPROVEMENTS TO THE ORNL MODEL

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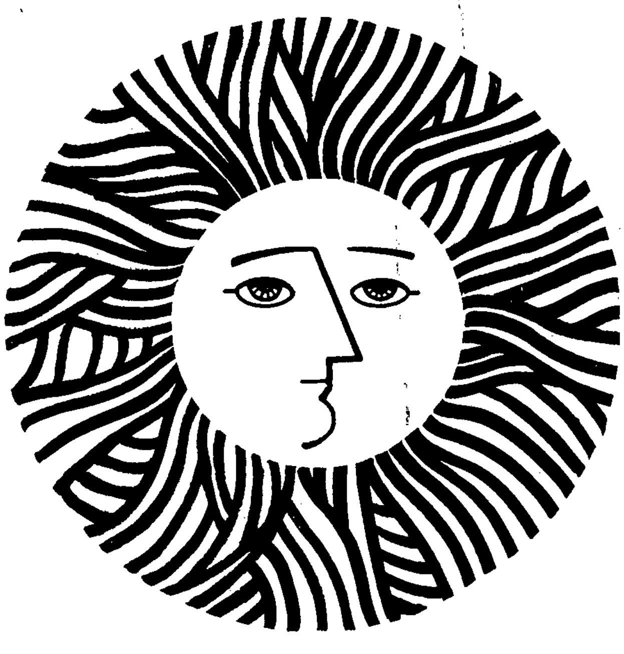

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ABSTRACT

The ORNL/LBL Residential Energy Demand Model incorporates major improvements in three areas: efficiency of appliances, current construction practice in new houses, and appliance retirements. The new methodology is more general, and provides energy demand estimates in better agreement with recent data. Key areas for future improvements are indicated, including: quantifying the uncertainty in model simulation, redefining the set of end uses, updating the algorithm, and broadening the model's applicability to different geographic areas.

A U.S. Department of Energy survey of appliance manufacturers was used to determine new appliance efficiencies. Similarly, surveys of current housing practices (e.g., ceiling insulation level) were used to estimate changes in heating and cooling energy requirements. Appliances are assumed to retire as a function of their age.

KEYWORDS

Energy demand model, residential energy, energy conservation, end use energy, appliance efficiency, appliance retirements, thermal

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integrity.

INTRODUCTION

Attempts to model future energy consumption have attracted great interest since 1974. The tools applied to this task are computer models, and the trend in modeling is toward greater disaggregation. Early attempts to estimate future energy demand assumed a direct relationship between economic growth and growth in energy demand, and concentrated on the national level. A better approach takes into account the effects of conservation efforts. Subsequently, the energy demand has been broken into sectors: transportation, industrial, commercial, and residential demands. Further insight was sought by further disaggregation in each sector so that the ultimate end uses of the energy came under consideration. In the residential sector, the principal end uses are space heating, water heating, air conditioning, lighting, refrigerating, cooking and other appliances.

The Oak Ridge National Laboratory (ORNL) developed a detailed end use model (Hirst and Carney, 1978), specifically intended for use in analyzing alternative energy policies for the United States.

This paper describes changes made to the ORNL model in the course of a specific application, the analysis of potential national Consumer Product Efficiency Standards (CPES), proposed by the United States Department of Energy (DOE). The ORNL model was selected as the implement to be used to assess changes in energy consumed and in consumer costs, both for equipment and for energy, resulting from the proposed efficiency standards.

The final model, called the ORNL/LBL Residential Energy Demand Model, incorporated changes in three areas of concern. First, the approach to changes in efficiency of new appliances was improved. Second, construction practice of new homes involves higher levels of insulation than in the past and should exhibit significant effects on energy consumed for space conditioning (heating and cooling). The model prior to modification accounted for changing efficiencies and housing characteristics in future years, but from an incorrect starting point. Third, the expected sales of appliances will depend not only on the number in stock, but also on the age distribution of existing units. A vintaging approach, in which the age distribution is updated each year, provides a better guide for future replacement sales.

EFFICIENCY OF NEW APPLIANCES

The ORNL model previously contained the assumption that, in the first year of a simulation (in this case 1977), the efficiency of a new appliance was the same as the efficiency of the average unit already in use. With the passage of time and increases in energy costs, manufacturers are providing, and consumers are purchasing, appliances with higher efficiencies. The disparity between the efficiency of a new unit and the unit it replaces will be increasingly significant when estimating future energy consumption. Table 2 shows the efficiency improvements since 1972 and 1975. In the old method, the 1978 new unit would have been assigned an energy consumption very close to that of the 1977 stock unit.

The ORNL model was capable of projecting future equipment efficiencies from a base year starting point. The improvement to the model involved adding an input that specified the efficiency of new units relative to the average stock unit in the initial year. This removes the constraint that these efficiencies had to be the same. In addition, the set of design options available for purchase in future years was readjusted to begin with the base year new unit rather than with the stock unit. The constraint that future appliances can not be less efficient than a 1978 unit was maintained.

Model: The efficiency of new units currently available in the marketplace is no longer linked to the efficiency of units already in use;

Input: New data on the efficiency of new units is considered explicitly; and

Output: Changes in energy consumption due to changing technology are better reflected in the resulting projection.

TABLE 2
EFFICIENCY IMPROVEMENTS SINCE 1972 IN RESIDENTIAL APPLIANCES

	Shipments-Weighted Energy Factors[a]			Percent Change[b] in Unit Energy Consumption Since 1975	
	1975	1978	1980	1978	1980
Furnaces - Gas	63.24	63.55	63.3	-0.5	-0.1
- Oil	73.65	75.20	75.7	-2.1	-2.7
					Since 1972
	1972	1978	1980	1978	1980
Room Air Conditioner	6.22	6.75	6.72	-7.9	-7.4
Central Air Conditioner	6.66	6.99	7.06	-4.7	-0.9
Water Heater - Electric	79.80	80.67	78.3	-1.1	+1.9
- Gas	47.35	48.17	47.9	-1.7	-1.1
Refrigerator/Freezer	4.16	5.09	5.51	-18.3	-24.5
Freezer	7.53	10.0	9.73	-24.7	-22.6
Range/Oven - Electric	42.8	53.6	43.25	-20.1	-1.0
- Gas	13.9	17.6	25.82	-21.0	-46.2
Dryer - Electric	2.61	2.59	2.88	+0.8	-9.4
- Gas	2.10	2.38	2.60	-11.8	-19.2

[a]1972, 1975, and 1978 values are from CS 179 surveys conducted by DOE. 1980 values are from Engineering Analysis for CPES.

[b][(SWEF (1975)/ SWEF (x)) -1]* 100, for year X.

CONSTRUCTION PRACTICE OF 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 actual energy consumption of new houses is more difficult to obtain, the characteristics of new houses are available. Such characterisics as: amount of ceiling insulation, wall insulation, glazing level, floor area, floor insulation, and window area are considered. Physical models of heat transfer in a house (such as DOE-2.1 Building Energy Analysis Program) were used to determine the annual energy consumption for heating and for cooling, based on the characteristics of the house. Table 3 shows the results. Correction for changes in the floor area of the house, efficiency of the heating system, and usage patterns are performed in addition to, and separate from, this calculation.)

TABLE 3.
ANNUAL ENERGY CONSUMPTION FOR HEATING AND COOLING (10^6 Btu*/yr)[a]

	SINGLE FAMILY		MULTI FAMILY	
	1977 Stock	1978 New	1977 Stock	1978 New
Central Space Heat				
Electric	174.90	116.66	69.62	61.06
Gas	105.58	54.48	43.20	35.25
Oil	177.70	91.69	70.98	57.92
Air Conditioning				
Room	24.30	19.22	9.97	9.68
Central	91.10	72.06	37.30	36.22

*11500 Btu = 1 kwh

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, than the average house already in existence. Similarly, the set of design options available in future years must begin with what is available in present-day new houses. The constraint that future new houses must be at least as efficient as 1978 new houses is retained.

The major changes are as follows:

Model: The heating energy requirements of new houses are distinguished from existing houses;

Input: Newer data on housing characteristics are utilized to generate the heating and cooling energy requirements;

Output: Changes in energy consumption due to changes in construction practice are better captured.

APPLIANCE RETIREMENTS

The model as originally written distinguished between purchase of appliances each year for new houses and purchase of appliances for installation in existing houses. Most of the latter are replacements of appliances that have reached the end of their useful service life. The original formulation uses an exponential retirement function, equivalent to assuming that a constant percentage of the existing appliances retire each year. In a population that is growing at a significant rate, this assumption is poor, since the most recently purchased appliance will not soon require replacement. The general solution to this problem involves keeping track of the vintage, or age distribution of all the appliances, and only retiring them at appropriate intervals after their year of purchase. This vintaging approach requires a more complex computer model, and a significant increase in computation time, but provides a more accurate representation of the real turnover of appliances.

A derivation of retirement functions was found in the literature (MTSC, 1980). A retirement function is an expression of the percent of appliances that retire as a function of the number of years since they were originally purchased. A comparison of the retirement function and the exponential assumption that it replaced is given in Figure 1. While the old formula retired about 5.1% of the existing appliances each year, regardless of their age, the new formulation retires no refrigerators until they

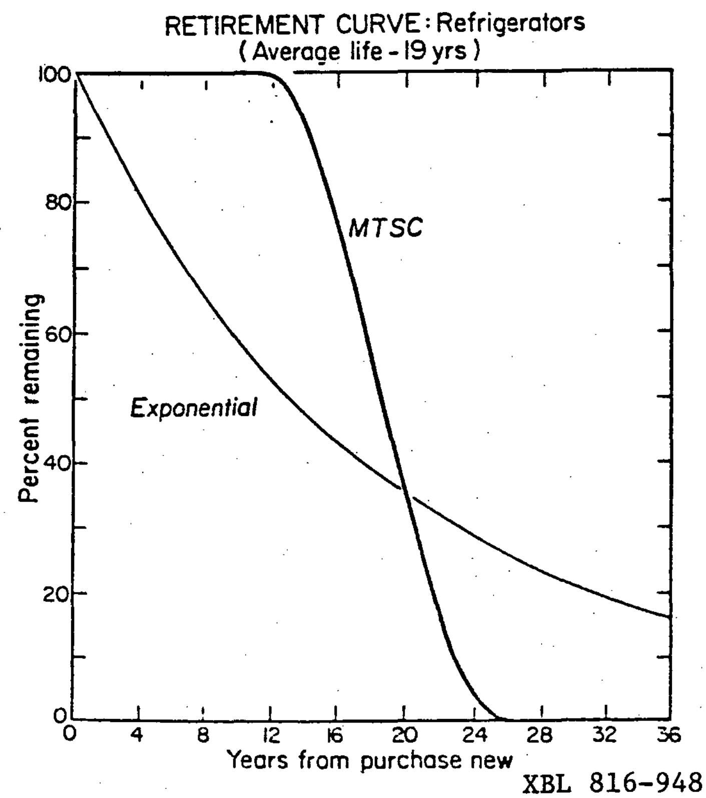

Fig. 1. Percent survivors vs. years since first purchase: Refrigerators

are 12 years old. (Presumably many refrigerators are sold as second-hand items, but continue to function under new ownership.) Also, the old formula allowed a number of very old refrigerators to go on operating for 40 years, while the new approach effectively eliminates refrigerators older than 26 years.

Model: A vintaging approach to the retirement of appliances has been added;
Input: A data set including both retirement function and historical shipments has been added;
Output: Sales of appliances to existing houses each year, and therefore future energy consumption by appliances, have been changed and are more consistent with industry estimates.

Table 4 illustrates the effect of these changes on estimates of appliance shipments, and includes a comparison with estimates of shipments provided by existing services.

Table 4. Annual Shipments in 1978 by Appliance Type

	Model Estimates		Industry Estimates		
	Old	New	MTSC[c]	CPES[d]	AHAM[e]
Refrigerator/Freezer	7049	5898	5939	6582	5890
Freezer	1935	2808	1404	1523	1521
Range/Oven	6829	5487	5279	10280[a]	3217[b]
Water Heater	8967	6800	6925	5608	-
Room Air Conditioner	1966	2545	2794	4038	4037
Central Air Cond.	2112	2202	2789	1857	-
Furnace	4475	2750	2853	2036	-
Clothes Dryer	3259	3002	3550	3696	3621

[a]Counting Rangetops and ovens separately.
[b]Electric only.
[c]Reference 7.
[d]Reference 5.
[e]Reference 8.

FUTURE DIRECTIONS

Modeling efforts have improved substantially in recent years. While forecasts of exactly what will come in the future are now--and will remain--impossible, model simulations can define the range of probable futures. More refined models will be sought for continuing policy analysis by governments concerned about national energy demands and resulting geopolitical consequences. Electric utility planners, energy suppliers, and conservation technologists will also be concerned with anticipating future energy and technology demands.

Considering the ORNL/LBL Residential Energy Demand Model as a framework, there are several areas in which changes need to be made.

- quantify and examine the uncertainty in the simulation
- redefine the set of end uses to unite space heating and cooling
- update historical econometric formulations, especially the fuel split algorithm
- consider the variety of decision segments involved in appliance purchase and use
- broaden the applicability of the model to utility service areas

Uncertainty

Just as the estimate of energy consumption in a future year is important, so is the uncertainty in that estimate. Prudence requires that utility or government planners prepare for the possibility that the "likely" estimate may be too high or too low. Rigid planning based on a single estimate of future demand could lead to disaster, or at least serious economic penalty.

The current model provides no estimate of uncertainty. Usually, the range of possible values is determined by sensitivity analysis, frequently involving one variable at a time. This is a poor way to estimate the range of values, since no probability is assigned to any of the values. A better method involves Monte Carlo simulation, but this is quite expensive and requires estimating the probability associated with different values of the key input variables. The model could be improved by estimating the uncertainties in the coefficients of its formulas, and the uncertainties in key variables, and then calculating the overall uncertainty in a few years of the simulation. Once performed, this task will provide a better understanding of where the greatest uncertainties lie. Then these coefficients or inputs should receive specific attention to reduce that uncertainty.

Space Conditioning

There are few linkages between end uses in the present model. Yet integration of end uses is likely to become an important issue. This is already the case for space conditioning. Space heating and air conditioning are already connected by the house characteristics (amount of insulation, window area, etc.). However, this connection is not done in a way that allows a good treatment of solar houses, particularly passive solar. Also, the high volume of sales of heat pumps warrants explicit treatment of this space conditioning option.

The general solution to these related concerns is to construct the model such that a single space conditioning end use is defined. Within that end use, a set of discrete options would be considered, such as a heat pump vs. gas furnace plus central air conditioner vs. electric resistance heat plus room air conditioner, etc.. The generalization will be completed if the decisions about housing retrofits, fuel choice for the heating unit, and efficiency choice are all combined.

The difficulty in modeling aggregate results will be in deciding what proportion of the consumers in a given year will avail themselves of the options. Perhaps the results of individual household modeling could contribute (Goett, in reference 2).

Decision Segments

Many appliances are purchased by people who will not be the ultimate users of the product. For example, space heating and water heating equipment is most often chosen by contractors or landlords, e.g., someone other than the person responsible for paying the utility bills. The criteria used by these different decision makers probably differs. It is likely that someone who is buying an appliance for his/her own use will be more concerned about the operating costs than will a landlord who is purchasing an appliance for use by a tenant. Home builders and contractors may be more concerned with keeping equipment costs low than with furnace efficiency. Even among purchases for personal use, the amount of concern about operating cost vs. capital costs may depend on the income level of the purchaser.

In order to better model actual decisions, it may be necessary to provide different decision-making formulations for different segments of society. While this will impose a significant increase in data requirements, it may provide a more accurate simulation.

CONCLUSION

The ORNL Residential Energy Demand Model has been modified to create the ORNL/LBL Residential Energy Demand Model. The original ORNL model provides a good tool for simulating future residential energy demand, and is a good framework for modifications that improve some important aspects of the simulation. The modifications described here incorporate the most recent data available in three areas of concern, in order to make the model a better representation of the changing reality of energy consumption.

The first area of concern is the improvement in efficiency of new products, relative to the units they are replacing. An industry-wide survey by the U.S. Department of Energy provided valuable data about the increased efficiency of new 1978 appliances relative to their older counterparts. This data was used in relaxing the constraint that equal efficiencies were assumed for stock and new units in the base year of the simulation.

The second modification is implemented in a manner similar to the first, but dealt with characteristics of newly constructed houses. The effect of increased insulation and glazing levels on heating energy requirements was included in the model by completing the distinction between stock and new houses.

The third modification involves keeping track of the age distribution of appliances, and using a retirement function to determine the number of units purchased in one year that retire in each later year. This is the major determinant of future purchases of appliances in existing houses.

All three modifications are consistent with recent data. All three modifications also lead to lower estimates of future residential energy demand in the United States than are obtained from the unmodified model. The structural changes to the model enable it to provide a more general, and more realistic methodology in these areas. While the input data will continue to be refined, the changes to the methodology were necessary to permit consideration of these concerns.

Many more issues have been raised that are difficult for the existing model to handle well. Some of the important issues and proposed changes to the modeling approach have been identified.

REFERENCES

1. Energy Modeling III: Dealing with Energy Uncertainty, Institute of Gas Technology, Chicago, Illinois, August, 1980.

2. End Use Modeling and Conservation Analysis, Electric Power Research Institute Workshop, Atlanta, Georgia, November, 1980.

3. E. Hirst and J. Carney, The ORNL Engineering-Economic Model of Residential Energy Use, ORNL/CON-24, Oak Ridge National Laboratory, Oak Ridge, Tennessee, July, 1978.

4. H. Herring, The Use of the NIECS Data Base in Validating the ORNL Residential Model, Lawrence Berkeley Laboratory, Berkeley, California, 1981. (in preparation)

5. U.S. Department of Energy, Conservation and Solar Energy, Office of Buildings and Community Systems, Economic Analysis, Energy Efficiency Standards for Consumer Products, June, 1980.

6. J. McMahon, The ORNL/LBL Residential Energy Demand Model, Lawrence Berkeley Laboratory, Berkeley, California, 1981. (in preparation)

7. R.B. Fechtel, E.R. Novicky, A.R. Wusterbarth, Energy Capital in the U.S. Economy, MTSC, Inc., Bethesda, Maryland, November, 1980.

8. "Trends and Forecasts. Factory Unit Shipments of Major Appliances," Association of Home Appliance Manufacturers, Chicago, Illinois, January 24, 1980.

9. Electric Load Forecasting: Challenge for the '80's, Utility Modeling Power First Working Group, EPRI EA-1536, Electric Power Research Institute, Palo Alto, California, September, 1980.