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Conservation
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Division of Buildings
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Community Systems

Energy and Economic Benefits of Residential Energy Conservation RD&D

Eric Hirst

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ABSTRACT

The ORNL residential energy model is used to evaluate the energy and direct economic effects of offering new technologies for providing residential services (e.g., space heating, water heating). These new technologies are assumed to be introduced as a consequence of government and private research, development and demonstration (RD&D) programs.

The energy savings due to the new technologies considered here increase from 0.1 QBtu in 1980 to 0.9 QBtu in 1990 and 1.9 QBtu in 2000. Present and projected RD&D programs sponsored by the Department of Energy (DOE) are expected to account for one-third of the cumulative energy saving of 20 QBtu.

Because these new systems are more energy-efficient than the conventional systems they replace, household fuel bills are reduced by $20 billion between 1977 and 2000. On the other hand, the higher initial cost of these advanced systems increases consumer costs on new equipment and structures by almost $3 billion. Thus, the net economic benefit to the nation's households is almost $18 billion. The DOE programs account for about 40% of this dollar saving.

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CONTENTS

ENERGY AND ECONOMIC BENEFITS OF RESIDENTIAL ENERGY CONSERVA RD&D

Eric Hirst

1. INTRODUCTION

This report evaluates the likely energy use and direct economic effects of developing and offering new residential energy-using technologies during the next several years. These evaluations are conducted with the ORNL residential energy use model.[1,2]

Seven different energy "futures" are evaluated with the ORNL energy model. The first (baseline) assumes that real fuel prices rise between now and the year 2000 as projected by the Department of Energy. In addition, the baseline includes the residential energy conservation regulatory and incentive programs authorized by the 94th Congress[3,4] and expanded upon in the President's *National Energy Plan*:[5] appliance efficiency standards, thermal performance standards for construction of new residences, and programs to encourage retrofit of existing housing units. Finally, the baseline assumes that no new residential energy technologies (e.g., advanced heat pumps, LITEK lamps, improved insulating materials) are developed and offered for sale between now and the year 2000.

The second, third, fourth, and fifth futures assume that new technologies are developed and become available during the next several years. These technologies are grouped as follows:

Structures, both new and existing
Heating and air conditioning equipment
Appliances and lighting
All of the above.

Comparisons between each of these cases and the baseline show the degree to which households purchase and use these new systems and the energy and economic consequences of doing so. For each case, we evaluate the benefits of these new technologies under two assumptions: the federal government sponsors energy conservation RD&D and the federal government does not sponsor such RD&D.* Differences in energy use and costs between cases show the effects of government RD&D (i.e., those benefits that accrue to the activities of the former ERDA Division of Buildings & Community Systems†).

Cases 6 and 7 explore the effects of buildings conservation RD&D programs under the assumption that fuel prices increase much more sharply than assumed for Cases 1-5. We develop a set of fuel prices to approximately reflect severe crude oil shortages as projected by the Central Intelligence Agency[6] and the MIT Workshop on Alternative Energy Strategies.[7] Case 6 is identical with the original baseline except for the much higher fuel prices. Similarly, Case 7 is the same as case 5 except for the higher fuel prices.

The major outputs from these runs are summarized in Tables 1 and 2. Table 1 shows national residential energy use for 1976, 1980, 1985, 1990, 2000, and for the 1977-2000 period for each of the simulations.‡ Table 2 shows the present worth (in 1977 at a real interest rate of 8%)

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*Research, development and demonstration.

†The cases discussed here do not encompass all the RD&D programs underway in DBCS. In particular, community energy systems are not included.

‡Energy use is presented in British units. 1 QBtu = 1 Quad = 10^{15} Btu. 1 Btu = 1,055 joules. Electricity use figures are in terms of primary energy (11,500 Btu/kwhr); that is they include losses in generation, transmission and distribution. Figures for gas and oil do not include losses associated with refining and transportation.

Table 1. Alternative residential energy projections: energy use

Case	Description	Energy use (QBtu) 1980	1985	1990	2000	Cumulative (1977-2000)	Average annual growth rate 1976-2000 (%)[a]
1	Baseline	16.7	17.5	18.9	21.6	447.2	1.2
Conservation RD&D Programs							
2	Structures	16.6	17.3	18.7	21.2	442.2	1.1
3	Heating & cooling equipment	16.7	17.3	18.5	20.7	438.5	1.0
4	Appliances & lighting	16.7	17.3	18.5	20.7	438.1	1.0
5	All RD&D	16.6	17.0	18.0	19.7	426.8	0.8
Higher Fuel Prices							
6	Baseline	15.1	14.3	15.3	17.6	374.8	0.3
7	All RD&D	15.0	13.8	14.2	15.2	349.8	-0.3

[a]The model's estimate of residential energy use was 16.3 QBtu in 1976.

Table 2. Alternative residential energy projections: direct economic effects

Case	Description	Present worth of cumulative (1977-2000) expenditures at 8% real interest rate (10^9 1975-$) Fuels	Equipment[a]	Structure thermal integrity[a]	Total
1	Baseline	603.4	0	0	603.4
Conservation RD&D Programs					
2	Structures	597.6	0	0.4	598.0
3	Heating & cooling equipment	595.5	0.6	0	596.1
4	Appliances & Lighting	594.5	1.9	0	596.4
5	All RD&D	583.0	2.5	0.1	585.6
Higher Fuel Prices					
6	Baseline	734.0	-7.2	0.1	726.9
7	All RD&D	698.4	-1.9	1.6	698.1

[a]The incremental capital cost figures for equipment and structures are relative to those for the baseline. For equipment, the increments include changes in both ownership and efficiencies. For structures, the increments include only thermal integrity changes. Thus, reductions in equipment expenditures shown for cases 6 and 7 are due to reduced purchases of household appliances because of the much higher fuel prices assumed.

of cumulative household expenditures (1977-2000) on fuels, efficiency improvements for equipment and structures, and total expenditures. These results show that RD&D programs to produce new residential systems yield large energy and economic benefits.

Before discussing each of the futures in more detail, we offer a few comments on the new technologies and their characterization within the energy model. First, each technology is defined within the model in terms of three characteristics:

Annual energy use for the new system relative to the typical 1970 system,
Capital cost for the new system relative to the typical 1970 system,
Year in which the new system is first offered for sale.

Although the inputs required for the energy model are quite simple, our confidence in the accuracy of the inputs is low. This is primarily because we are dealing with systems that do not yet exist. The technology definitions used in our analyses are based on conversations with program managers in the Division of Buildings & Community Systems (DBCS) and on several studies prepared by and for the Division.[8-13] Efforts are underway within DBCS to improve and validate these project inputs. These audits, plus outputs from initial RD&D projects, will provide continued refinement of the data inputs.

Second, we are unsure how additional research and operating experience will affect these new systems over time. For example, the initial cost for new systems might decline as manufacturers sell more and more units (i.e., the "learning curve" phenomenon). To approximately account for further changes, we assume that system efficiencies are improved by

10% five years after initial introduction with no increase in capital cost and by another 10% ten years after inital introduction.

Third, the definitions assume implicitly that new systems are identical to existing systems except for their cost and efficiency characteristics. That is, consumer perceptions concerning the safety, reliability, maintenance, noise, convenience, and other characteristics of the new system are assumed the same as for existing systems.

Fourth, we assume that these RD&D programs succeed in bringing new technologies to the market place. That is, we do not allow for RD&D failures. This assumption is probably not critical because we treat groups of projects together (e.g., heating and air conditioning equipment) rather than individual projects (e.g., Stirling/Rankine gas-fired heat pump). Although individual projects might fail, it seems unlikely that a generic class of projects will yield no commercial products.

Finally, the estimated benefits of new technologies depend strongly on the assumptions used to develop the baseline. We assume that the residential energy conservation programs in the *National Energy Plan* are fully implemented in the baseline. If the programs are weaker or delayed, then the energy and economic benefits of RD&D programs will be higher than estimated here.

In addition to the uncertainties and assumptions discussed above, results are subject to possible errors and uncertainties due to the model structure and coefficients (see Section 8).

The remainder of this report is organized as follows. Section 2 describes the inputs for our baseline case and the consequent model outputs. Sections 3, 4, and 5 discuss RD&D programs in each of three areas (structures, heating and cooling equipment, appliances and lighting). The energy and economic effects of introducing new technologies are evaluated for each group of projects for the 1977-2000 period. Section 6 evaluates the effects of the combined RD&D program, both with and without government involvement. Section 7 discusses the benefits of the combined RD&D program assuming much higher fuel prices. Finally, Section 8 reviews the different futures and summarizes the likely effects of each.

2. BASELINE PROJECTION

Inputs to the ORNL energy use model required to develop a projection include: population, fuel prices, per capita income, and specifications for government conservation programs (e.g., appliance efficiency standards, tax incentives for retrofitting homes, fuel price increases, development of new technologies). Each of these inputs must be provided for the 1970 2000 period.

We assume that population grows according to the Bureau of the Census Series II projection.[14] Per capita income is derived from a recent Data Resources, Inc. projection of Gross National Product (GNP) prepared for FEA[15] and the Series II population projection.

Projections of household formation and stocks of occupied housing units are obtained from our housing model using the DRI per capita income and Census population projections.[1] In developing our estiamtes of housing stocks, we assume that trends in housing choices (among single-family, multi-family, and mobile homes) between 1960 and 1970 will continue through the end of the century.[1] Table 3 shows the values of population, households, housing distribution, and per capita income used in all projections discussed in this report.

Table 3. Inputs assumed for all projections of residential energy use

	Population (10^6)	Households (10^6)	Distribution of occupied housing units (%) single-family	multi-family	mobile home	Per capita income (1975-$)
1970	205	63	69	27	3	5,420
1975	213	71	67	29	4	5,850
1976	215	72	67	29	4	6,050
1980	223	81	65	31	5	7,150
1985	234	91	63	32	5	7,970
1990	245	99	62	32	6	8,890
2000	262	114	61	33	6	10,570

Sources: refs. 1, 14, and 15.

The fuel price trajectories used as inputs to our model for this and succeeding projections are obtained from the Federal Energy Administration[15] and the Brookhaven National Laboratory[16]. As Fig. 1 shows, these projections indicate a substantial increase in real gas prices (average annual growth of 2.3% between 1976 and 2000) and moderate increases in electricity (0.9%/year) and oil (1.2%/year) prices.

Finally, the baseline includes the residential energy conservation programs authorized by the 94th Congress[3,4] and proposed in the *National Energy Plan:*[5] appliance efficiency standards for 1980, thermal performance standards for new construction in 1978 and stronger standards in 1980, and several programs to encourage weatherization (retrofit) of existing housing units. Our assumptions concerning each of these programs and their effects on energy use and household economics are detailed in ref. 2.

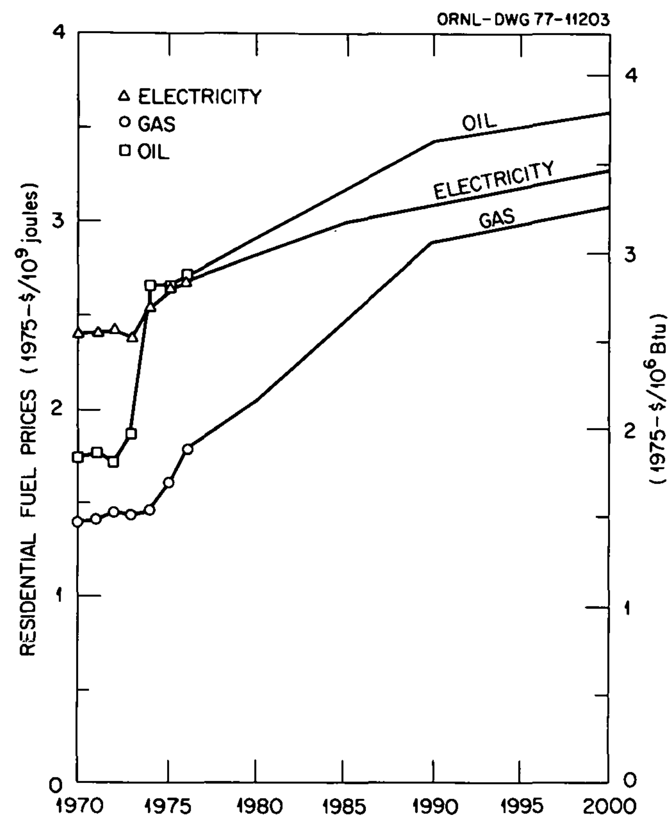

Fig. 1. Assumed fuel prices to the year 2000. Recall that electricity is in terms of primary energy.

Outputs from the energy model, given these inputs, show residential energy use growing from 16.3 QBtu in 1976 to 16.7 QBtu in 1980, 18.9 QBtu in 1990, and 21.6 QBtu in 2000; see Fig. 2. The average growth rate during this 24-year period is 1.2%/year. Thus, the combined effect of slower population growth, rising fuel prices, and federal regulatory/incentive conservation programs is to sharply reduce energy growth from its historical rate of 4.0%/year (1950-1972). Thus, energy use in the year 2000 is projected to be less than half of what it would be if historical trends continued to the end of the century.

The contribution of different fuels to the total changes during the projection period, as shown in Fig. 2. Because of the sharp increases in oil prices during the early 1970s and the assumed rapid increases in gas and oil prices, electricity's share of household energy use increases from 45% in 1976 to 67% in 2000. Electricity's share also increases because of rising ownership of air conditioning equipment and food freezers. The shares accounted for by gas and oil decline from 34% and 17% in 1976 to 25% and 7% in 2000. "Other" fuels also contribute a declining portion of the total, down from 4% to 1%.

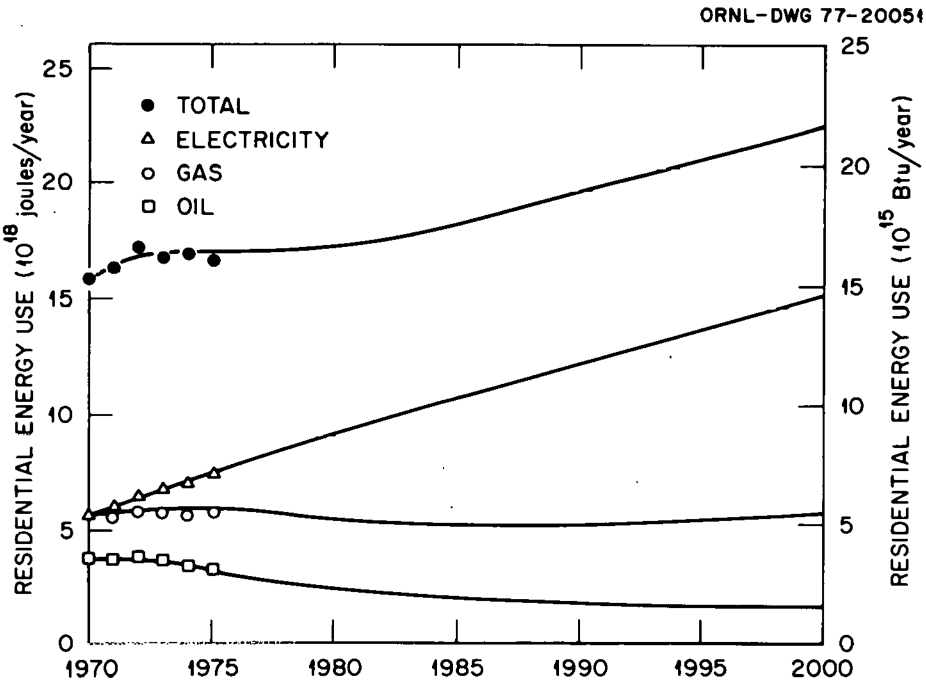

Fig. 2. Baseline projection of residential energy use to the year 2000, including the *National Energy Plan* residential conservation programs.

3. STRUCTURES

RD&D projects in this area relate to reductions in winter heat loss and summer heat gain through the shell of a building (floor, walls, windows, doors, and roof) and reductions in the costs of improving structure thermal performance. Projects in this area involve both construction of new housing units and weatherization of existing units.[8,9,10,12]

Several projects involve the thermal characteristics and costs of insulating materials. Surprisingly, stated "R" values of commercially-sold insulation may not accurately reflect actual performance of the material. Projects are underway to evaluate R values under both laboratory and field conditions. Another project is testing R values of insulation taken from the walls and ceilings of existing housing units.

A detailed computer code to calculate hour-by-hour heating and cooling loads for buildings is being developed. This code, called CAL/ERDA, will be much easier to use and much less expensive to run than are existing codes.

Another project deals with the value of attic ventilation in reducing air conditioning loads. Data and analysis from this effort will show the value of roof-top turbine ventilators, power ventilators, soffit and gable vents, and whole house attic fans. In some regions, these options may provide low-cost, energy-efficient alternatives or supplements to conventional air conditioning.

Additional insulation can generally be easily added to attics in existing homes. Research underway at Princeton University will experimentally determine the effects of additional insulation on winter heating and summer air conditioning fuel uses.

Infiltration of outside air accounts for roughly one-third of the annual cost of heating and air conditioning a typical single-family home. Unfortunately, present understanding of the determinants of infiltration and the ability to accurately and inexpensively measure infiltration are inadequate. Results from research projects to develop simple, reliable, and inexpensive procedures for measuring and calculating infiltration, coupled with techniques for reducing infiltration in new and existing structures, could provide large energy benefits.

Better design of windows (glazing type, location in house, and shading) could increase winter heat gains and reduce summer heat gains.

Measurement of heat losses in both new and existing houses with aerial infared photography may yield good qualitative information at very low cost (less than $1/house).

The overall thrusts of these and other projects are to:

- provide reliable information on the performance of building components
- improve techniques for evaluating building performance, both analytically and on-site
- develop improved methods for insulating homes, reducing infiltration, and wisely using solar energy (via windows).

Successful projects in these areas will allow development and implementation of cost-effective building thermal performance standards (in response to ECPA[4]), and more nearly optimal weatherization of existing housing units (in support of the NEP retrofit programs[5]).

In our analysis, we assume that the combination of these and other projects is to reduce the annual heat loss in a typical new housing unit by 20-30%. Figure 3 shows the relationships between annual heat loss through the shell of a new single-family unit as functions of the incremental capital cost to reduce heat losses. The upper curve shows the relationship with today's technologies and the lower curve shows assumed improvements due to the combination of private and government RD&D programs. Similar relationships for new mobile homes are shown in Fig. 4.

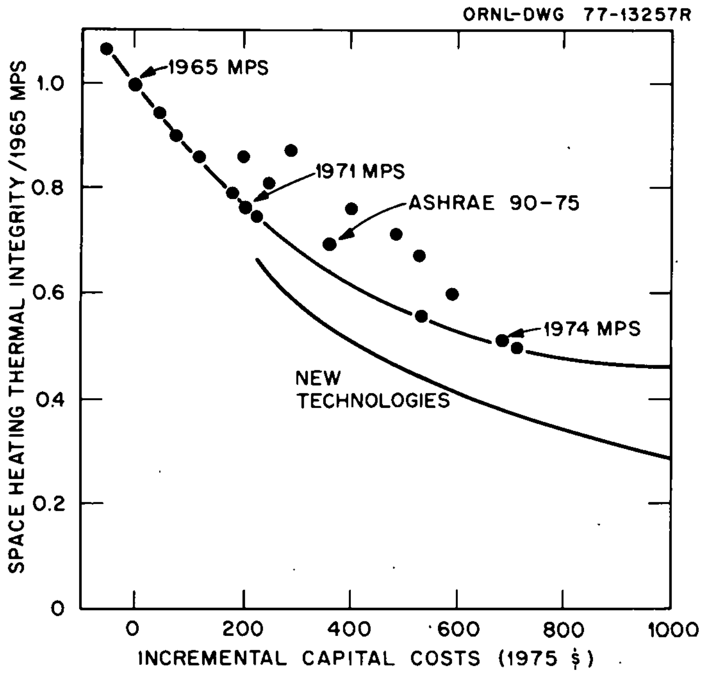

Fig. 3. Annual space heating load for new single-family units versus increased capital costs: New York, N.Y. The top curve shows the "technological possibilities" with today's technologies; the bottom curve shows the possibilities with improved (new) technologies.

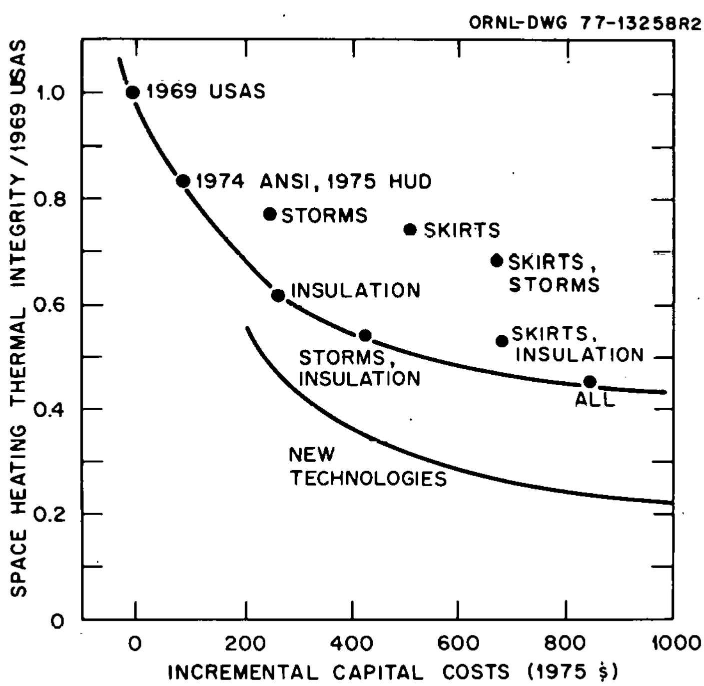

Fig. 4. Annual space heating load for new mobile homes versus increased capital costs: Atlanta, Ga.

For existing housing units, we assume that these RD&D projects do not affect the number of homes to be retrofit (the *National Energy Plan* already assumes that 90% of the single-family units will be retrofit by 1985). We assume that these projects reduce the annual heat loss by 10% for homes retrofit after 1979.

Table 4 shows the estimated energy and economic effects of improving the technologies for weatherizing new and existing structures. Annual energy savings increase from 0.1 QBtu in 1980 to 0.2 QBtu in 1990 and 0.4 QBtu in 2000. The cumulative energy saving of 5.1 QBtu due to the development of these new technologies is split 60:40 between electricity and fossil fuels. Development and implementation of these technologies reduce the present worth of household fuel bills by $5.8 billion and increase the cost of structures by $0.4 billion.* Thus the total benefit to the nation's households is $5.4 billion.

Table 4 also shows the contribution of DOE projects to the annual energy savings and the cumulative effects. We assume that the sole effect of DOE projects is to hasten successful commercialization of these new energy technologies by three years, from 1981 to 1978. Therefore, the relative DOE contribution declines over time: from 100% of annual energy savings in 1980 to 36% in 2000. Model results suggest that DOE projects account for 60% of the cumulative energy and 50% of the economic benefits of these projects.

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*The very slight increase in structure costs because of these RD&D projects suggests that the major effect of these new technologies is to reduce the cost of meeting the assumed NEP thermal performance standards.

Table 4. Energy and economic effects of new residential technologies: new and existing structures

	Annual energy savings (QBtu)			
	1980	1985	1990	2000
Electricity	0.03	0.09	0.12	0.25
Gas	0.02	0.05	0.06	0.11
Oil	0.01	0.03	0.03	0.03
Total	0.06	0.17	0.21	0.39
% of total savings due to DOE programs	100	88	67	36

Cumulative (1977-2000) energy and economic effects

Energy (QBtu)		Economic[a] (billion 1975-$)	
Electricity	3.0	Fuels	5.8
Gas	1.5	Equipment	-
Oil	0.6	Structures	-0.4
Total	5.1	Total	5.4
% DOE	62	% DOE	48

[a]Present worth calculations are performed with a real interest rate of 8%.

The present worth of current and projected DOE RD&D projects in this area is about $20 million.* With a net economic benefit to the nation's households due to these projects of $2.6 billion, the benefit/cost ratio for government expenditures is about 130. Thus, even if a sizable fraction of the DOE projects fail to yield commercial systems, the economics of these RD&D programs are still likely to be favorable.

4. HEATING AND AIR CONDITIONING EQUIPMENT

The RD&D projects evaluated here concern improved systems for heating, ventilating, and air conditioning (HVAC) homes. These systems

*The present worth represents the discounted (at a real interest rate of 8%) present-day value of the expected federal RD&D expenditures over the next ten years. Past expenditures (before FY-1977) are included with a zero discount.

include advanced electric heat pumps, the annual cycle energy system (ACES), gas-fired heat pumps, improved gas and oil furnaces, and high-efficiency compressors for room air conditioners.[8,10,11,13]

Projects dealing with electric heat pumps will develop and demonstrate systems with higher motor/compressor efficiencies, variable speed compressors, rotary compressors, increased heat exchanger surface, and improved fan design. Another project involves detailed computer simulation of heat pump performance under a variety of conditions. Such a mathematical model can aid in the design of improved components and systems. Figure 5 shows relationships between annual energy use for

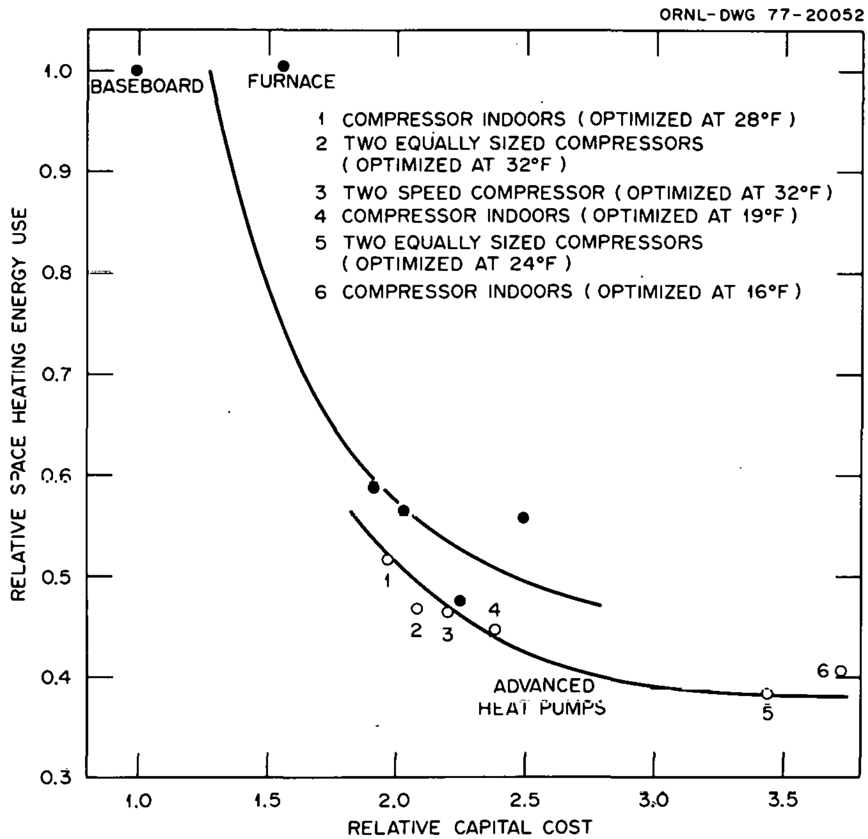

Fig. 5. Annual space heating energy use for electric heating systems versus capital cost. (Systems shown are for a single-family home in Atlanta, Ga. The closed circles represent existing technologies; the open circles represent advanced technologies.)

space heating and initial cost for present-day electric heating systems and advanced (forthcoming) heat pumps. For example, these curves suggest that RD&D programs such as those described above will produce a heat pump that uses 15% less energy than today's with no increase in capital cost.

Two different types of gas-fired heat pumps are being investigated. One uses an absorption unit and should be commercially-available in the early 1980s. The projected characteristics for this system indicate a 53% reduction in gas use for space heating and an 85% increase in capital cost (relative to a conventional gas-fired furnace).

The second approach uses a heat engine (rather than an electric motor) to drive the refrigeration cycle. Waste heat from the engine is also used for space heating. DOE, the American Gas Association, and General Electric are developing a Stirling/Rankine gas-fired heat pump. The system is expected to use only half as much gas for heating and cost almost 70% more than a conventional gas furnace. Both conventional and advanced gas space heating systems are shown in Fig. 6.

Other projects deal with improvements to gas and oil furnaces (e.g., reduced burner rates, improved flue designs, improved/larger heat exchangers); see Fig. 6. These projects deal less with development of new technologies and more with demonstration of known technologies.

Improvements in motor/compressor performance for room air conditioners are being investigated in ongoing projects. These projects are expected to yield high-efficiency motor/compressors with small increases in their cost.

Successful projects related to improvements in the performance of residential heating systems will make it easier for manufacturers to

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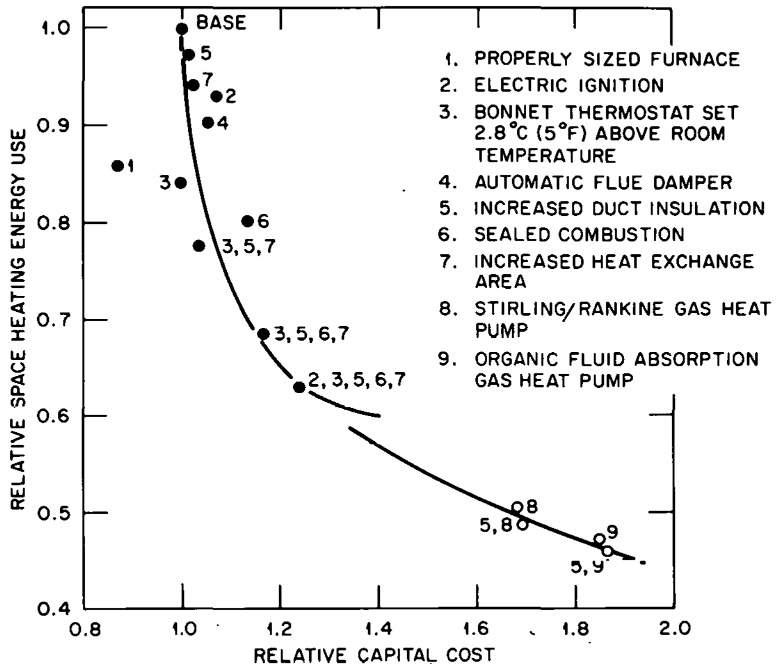

Fig. 6. Annual space heating energy use for gas-fired heating systems versus capital cost. (Systems shown are for a single-family home in Philadelphia, Pa.)

meet the appliance standards under EPCA;[3] these projects will also form the technical and economic basis upon which future standards might be established. In addition, these projects (particularly the demonstration phases) will help to overcome informational and institutional barriers to the implementation of energy-efficient heating systems.

Table 5 shows the estimated energy and economic effects of developing improved space heating systems. Annual energy savings increase from 0.02 QBtu in 1980 to 0.4 QBtu in 1990 and 1.0 QBtu in 2000. The cumulative energy saving of 8.7 QBtu is almost double the savings estimated due to structures RD&D. This is primarily because the likely NEP standards for appliances are much less strict than are those for new structures.[2]

Table 5. Energy and economic effects of new residential technologies: HVAC equipment

	Annual energy savings (QBtu)			
	1980	1985	1990	2000
Electricity	0.01	0.09	0.25	0.70
Gas	0.01	0.05	0.11	0.27
Oil	--	--	--	--
Total	0.02	0.14	0.36	0.97
% of total savings due to DOE programs	100	50	25	12

Cumulative (1977-2000) energy and economic effects

Energy (QBtu)		Economic[a] (billion 1975-$)	
Electricity	6.2	Fuels	7.8
Gas	2.5	Equipment	-0.6
Oil	-	Structures	-
Total	8.7	Total	7.2
% DOE	22	% DOE	32

[a]Present worth calculations are performed with a real interest rate of 8%.

Two-thirds of the cumulative energy saving is electricity. Only part of the electricity saving is due to improved heat pump and air conditioner performance; the rest is due to shifts in heating fuel choice from electricity to gas and oil. Presumably, market-shifts occur because of the larger efficiency increases in gas and oil systems.

Model results show that installations of advanced electric heat pumps increase steadily over time, from 30 thousand in 1980 to 200 thousand in 1990 and 320 thousand in 2000. Similarly, installations of gas-fired heat pumps increase from 50 thousand in 1981 to 310 thousand in 1990 and 620 thousand in 2000.

Implementation of these improved HVAC systems reduces the present worth of household fuel bills by almost $8 billion. Partly offsetting this savings is the increased cost of more efficient equipment ($0.6 billion).

The DOE contribution to the cumulative savings is 1.9 QBtu and $2.3 billion. The present worth of projected DOE budgets for these RD&D projects is about $40 million; this yields a benefit/cost ratio of 57. These estimates are based on the assumptions that commercialization of advanced electric heat pumps will be hastened by four years, gas-fired heat pumps and advanced oil burners by two years, and improvements to room air conditioners by ten years.

5. APPLIANCES AND LIGHTING

This section deals with residential end uses other than heating and cooling: the major ones are water heating, refrigerators, freezers, and lighting.[10, 13] Altogether, these (and other minor appliances) account for about 40% of residential energy use.

Two DOE projects deal with development and demonstration of electric heat pump water heaters. These water heaters are likely to use only half as much energy for water heating and cost more than twice as much as conventional electric water heaters (see Fig. 7).

Another project deals with improvements to conventional gas water heaters. DOE plans to support development and laboratory testing of high-efficiency units followed by a field testing program.

A similar development and field demonstration project involves improvements to refrigerators. The development phase will evaluate energy saving options such as optimized insulation thicknesses, efficient evaporator and condenser configurations, door seal improvements, improved defrost control, and improved evaporator fan systems.

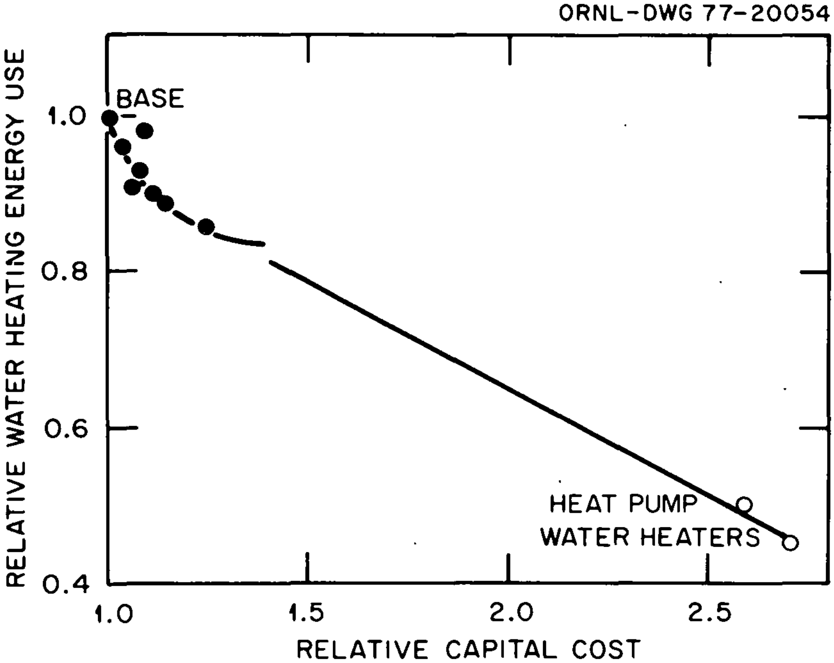

Fig. 7. Annual water heating energy use for electric water heating systems versus capital cost.

Other projects deal with "integrated appliances." These are systems that provide more than one residential function. For example, a combination space and water heating system being developed conserves energy by using the same heat source (either a gas or oil burner) to provide both functions. Such a system might cost $125 more than a separate furnace and water heater. However, the combined system is expected to require 34 million Btu/year less for space and water heating in a typical home than would the separate systems.

Another integrated appliance involves central air conditioning and electric water heating. Waste heat from the air conditioner (normally rejected to the outside air through the condenser) is used to preheat water. This integrated system is likely to cost $300 more than separate air conditioning and water heating units. Its annual energy saving is estimated to be 29 million Btu.

The major residential lighting project involves the LITEK lamp. This is an electrodeless flourescent light with an ordinary screw-type base. The LITEK lamp uses 70% less energy than conventional incandescent bulbs and does not require a new fixture for its use. Thus, households can replace worn-out bulbs with LITEK lamps without a change in fixture.

Table 6 shows the estimated energy and economic effects of developing these improved appliances and the LITEK. Annual energy savings increase from 0.03 QBtu in 1980 to 0.4 QBtu in 1990 and 0.9 QBtu in 2000. The cumulative energy saving of 9.1 QBtu is slightly larger than that due to improved HVAC systems. Most of the saving is electricity (80%) because refrigerators, freezers, and lights are all electrically-operated. The results in Table 6 show a slight saving in oil even

Table 6. Energy and economic effects of new residential technologies: appliances and lighting

	Annual energy savings (QBtu)			
	1980	1985	1990	2000
Electricity	0.02	0.17	0.32	0.70
Gas	0.01	0.03	0.06	0.11
Oil	--	0.02	0.03	0.07
Total	0.03	0.22	0.41	0.88
% of total savings due to DOE programs	100	64	44	18

Cumulative (1977-2000) energy and economic effects

Energy (QBtu)		Economic[a] (billion 1975-$)	
Electricity	7.2	Fuels	8.9
Gas	1.2	Equipment	-1.9
Oil	0.7	Structures	-
Total	9.1	Total	7.0
% DOE	36	% DOE	44

[a]Present worth calculations are performed with a real interest rate of 8%.

though no improvements in oil water heating systems are assumed. The saving is due to shifts in water heating fuel choice from oil to the improved gas and electric systems.

Consider electric heat pump water heaters as an example of the market penetration of these new systems. Model results show that installations increase from 50 thousand in 1980 to 750 thousand in 1990 and 1.39 million in 2000.

Development of these new technologies reduces the present worth of household fuel bills by almost $9 billion. This is partly offset by increases in the capital costs for these new systems of almost $2 billion.

The DOE contribution to these savings is estimated at 3.3 QBtu and $3.1 billion. This economic benefit should be compared with the projected DOE RD&D expenditure of about $10 million, yielding a benefit/cost ratio of 300. This assumes that DOE projects advance commercialization of advanced water heaters by six years, high-efficienty refrigerators by ten years, and LITEK by four years. The DOE benefits of these appliance projects are large in both absolute terms and relative to the estimated DOE benefits for structures and HVAC equipment. This is so because commercialization of these appliance systems is accelerated more than for the other technologies.

6. ALL NEW TECHNOLOGIES

Table 7 shows the estimated energy and economic benefits of offering all the new residential technologies discussed earlier. The overall annual and cumulative energy savings are smaller than the sum of the individual savings from Tables 4, 5, and 6 because of interactions among the HVAC equipment and structure improvements.

Table 7. Energy and economic effects of new residential technologies: all technologies

	Annual energy savings (QBtu)			
	1980	1985	1990	2000
Electricity	0.05	0.32	0.62	1.41
Gas	0.03	0.12	0.22	0.44
Oil	0.01	0.05	0.06	0.08
Total	0.09	0.49	0.90	1.93
% of total savings due to DOE programs	100	69	40	20

Cumulative (1977-2000) energy and economic effects

Energy (QBtu)		Economic[a] (billion 1975-$)	
Electricity	14.3	Fuels	20.3
Gas	4.9	Equipment	- 2.5
Oil	1.2	Structures	- 0.1
Total	20.4	Total	17.7
% DOE	37	% DOE	41

[a]Present worth calculations are performed with a real interest rate of 8%.

The energy savings increase over time, reaching 1.9 QBtu in 2000; see Fig. 8. The saving in 2000 represents 9% of the baseline residential energy use. The cumulative energy saving of 20 QBtu represents almost 5% of the baseline. 70% of the cumulative saving is electricity; gas and oil account for 24% and 6%, respectively. More than one-third of the cumulative energy saving can be attributed to DOE programs: 7.5 QBtu.

The total economic benefit to households of these new technologies is $17.7 billion. Of this total, $7.3 billion can be attributed to the DOE programs. The present worth of the DOE budget for residential RD&D

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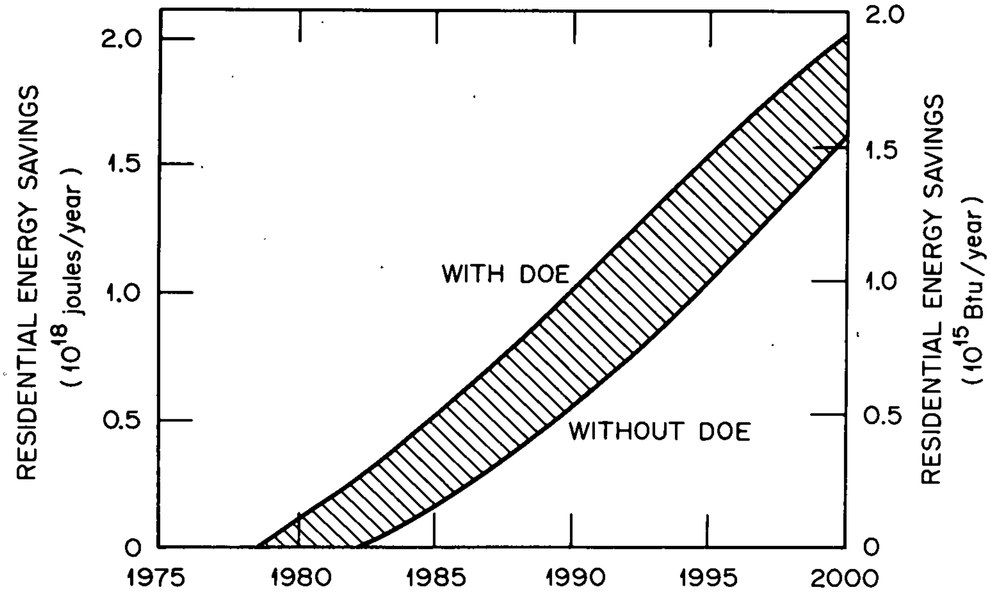

Fig. 8. Energy savings in the residential sector due to development of new energy-using technologies, with and without DOE RD&D programs.

programs is about $70 million. This suggests a benefit/cost ratio for DOE programs of 100.

7. EFFECTS OF MUCH HIGHER FUEL PRICES

Here we evaluate the benefits of RD&D programs, assuming that fuel prices increase sharply in the 1980's. We use the April 1977 CIA estimates of world oil resources as the basis for this analysis;[6] see also ref. 7. According the the CIA, crude oil import prices are likely to rise to $26.50/bbl by 1985 (from a present level of about $13/bbl) because of growing demand and declining supply. We developed a set of residential fuel price trajectories for oil, gas, and electricity on the basis of this higher crude oil price.

We assume that the price of distillate fuel oil to residential customers will be $3.50/bbl higher than the crude oil price. We assume that the price of natural gas will be deregulated gradually and will approach the distillate fuel oil price in terms of $/Btu. After 1985, the prices of gas and oil are assumed to be the same. Electricity prices also rise but not as rapidly as do gas and oil prices.

Fuel prices in 1985 are substantially higher in this case than in the baseline: 43% higher for electricity, 96% for gas, and 55% for oil By the year 2000, these differences have moderated somewhat.*

The effect of the "CIA" prices is to reduce residential energy growth from 1.2%/year (case 1) to 0.3%/year (case 6). The reduction in energy use is due to three factors: improved efficiency for equipment and structures, reduced ownership of appliances, and reduced usage rates.

We made a final run (case 7) to evaluate the energy and economic benefits of residential RD&D programs under this assumption of high fuel prices; see Table 8. Annual energy savings increase from 0.1 QBtu in 1980 to 1.1 QBtu in 1990 and 2.5 QBtu in 2000. The cumulative energy saving of 25 QBtu is almost 25% greater than the saving shown in Table 7 (moderate fuel price increases). The energy savings with very high fuel prices are always higher - in both absolute and relative terms - than with moderate fuel prices. This suggests that development of new residential technologies is even more important if fuels become very scarce and expensive.

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*Fuel prices are higher in the year 2000 (relative to the preceeding cases) by 34% for electricity, 80% for gas, and 54% for oil. Fuel prices increase between 1975 and 2000 at the following average annual rates with these higher prices: 2.1% electricity, 5.1% gas, and 3.0% oil.

Table 8. Energy and economic effects of new residential technologies: all technologies, relative to "CIA" prices

	Annual energy savings (QBtu)			
	1980	1985	1990	2000
Electricity	0.05	0.32	0.84	2.05
Gas	0.04	0.10	0.15	0.21
Oil	0.02	0.08	0.13	0.20
Total	0.11	0.50	1.12	2.46
% of total savings due to DOE programs	100	68	44	20

Cumulative (1977-2000) energy and economic effects

Energy (QBtu)		Economic[a] (billion 1975-$)	
Electricity	19.3	Fuels	35.6
Gas	3.0	Equipment	- 5.4
Oil	2.7	Structures	- 1.4
Total	25.0	Total	28.8
% DOE	36	% DOE	39

[a]Present worth calculations are performed with a real interest rate of 8%.

This conclusion is also supported by model results on the economic effects of these programs. As Table 8 shows, the reduction in present worth of fuel bills is almost $36 billion. This is partly offset by higher capital costs of almost $7 billion. Thus, the net economic benefit is almost $29 billion, more than 50% larger than the economic benefit shown in Table 7.

The contribution to these energy and economic benefits from the DOE programs is roughly the same for both sets of assumed fuel prices: 35 - 40% of total benefits. With the high fuel prices assumed here, the DOE-related benefits amount to 9 QBtu and $11 billion.

8. CONCLUSIONS

We used a detailed engineering-economic model of residential energy use to evaluate the energy and economic effects of developing new technologies that provide residential end uses. These technologies were evaluated in groups: structures, HVAC equipment, appliances & lighting, and all systems. We also examined these effects under the assumption that fuels would become very scarce and expensive in the early 1980's. In each analysis we made two runs, to determine the likely effect of government RD&D programs (Department of Energy) relative to those conducted in the private sector.

Our results strongly suggest that residential conservation RD&D programs in all areas are likely to yield large energy and economic benefits. As Fig. 9 shows, the dynamics of RD&D benefits differ sub-

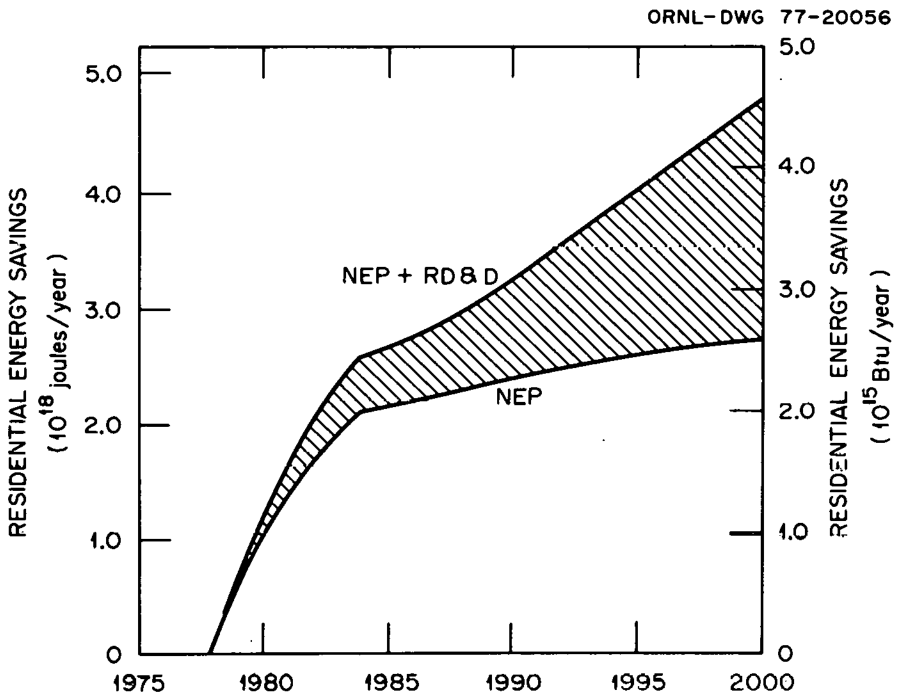

Fig. 9. Residential energy savings due to implementation of the *National Energy Plan* conservation programs and RD&D programs.

stantially from those due to government regulation and incentives. The energy savings due to the *National Energy Plan* programs increase rapidly through the early 1980s and then increase slowly to the end of the century. RD&D benefits, on the other hand, grow more slowly at first, but then (in the 1990s) grow much more rapidly than do the benefits of regulation and incentives. This suggests the need for a combined government strategy: regulations and incentives for the short-term and new technologies for the long-term. The results portrayed in Figs. 8 and 9 also emphasize the need for prompt attention to RD&D. Because of the long lead-time associated with the energy and economic benefits from these new technologies, it is important to begin these projects promptly.

In addition to the direct energy and economic benefits of RD&D programs discussed here, two other consequences deserve mention. The first concerns increased choices. Because new systems for satisfying end uses are developed, consumers have a wider set of choices; because these new systems have lower lifecycle costs than do conventional systems more households own more systems and are able to use them less frugally. For example, the development of high efficiency food freezers allows more households to purchase freezers. The development of gas-fired heat pumps allows households to be less frugal (to reduce the amount of thermostat setback) in their use of heating systems.

The second concerns potential synergisms between government RD&D and government regulation. Development of appliance and construction standards spurs industrial RD&D efforts. Government sponsorship of RD&D projects allows for the development and implementation of standards that require greater increases in energy efficiency.

The ORNL energy model used to conduct this analysis contains many limitations and assumptions, discussed in refs. 1 and 2. A few of these are particularly important with respect to interpretation of the results presented here:

1. The model contains a simple alogrithm to determine the extent and pace with which manufacturers and households produce and purchase improved equipment and structures in response to fuel price changes. Lack of both theory and data prevent us from adequately validating this portion of the energy model. If the model overestimates the responsiveness of the market system to fuel price changes, then our estimates of the benefits of RD&D programs (both private and government) are overstated.

2. The model equations are sensitive to the operating and capital costs of different systems. As discussed in the Introduction, the model does not consider non-economic differences among systems such as reliability, safety, and noise. It seems likely that consumers will be reluctant to purchase new systems that differ substantially from existing systems (i.e., they are likely to be risk-averse); thus our estimates of the energy and economic benefits of these new technologies are probably overstated.

3. Inputs to the model on fuel prices, government regulatory/incentive programs, and new technologies strongly influence the results. Had we assumed higher fuel prices (see Section 7) and weaker regulatory/incentive programs, then our estimated benefits due to RD&D programs would have been higher. On the other hand, if the inputs on new technologies are optimistic with respect to efficiency improvements, cost

reductions, and date of initial commercialization; then we have over-estimated the RD&D-related benefits. Assumptions from the DOE program managers on the number of years that commercialization is accelerated because of DOE projects strongly influence the estimated benefits of the DOE RD&D programs.

4. Many of the new technologies considered (especially those related to space heating and air conditioning) have strong regional characteristics. For example, heat pump performance is higher in the south than in the north. The economics of these systems also vary across regions because of climate and fuel price differences. The analyses presented here are national; that is, they average equipment performance, fuel prices, and climatic conditions over all regions. (We are discussing with our DOE sponsors the possibility of repeating this analysis for each of the ten Federal regions, as we did for the NEP programs.[17])

Despite these caveats and those discussed in the Introduction, it seems clear that development of new residential energy technologies is likely to yield large energy and economic benefits to the nation. These benefits increase over time as more and more new systems are installed and as fuel prices continue to increase. The estimated benefits due to federal sponsorship of RD&D programs are very much higher than the costs to the government.

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REFERENCES

1. E. Hirst, et al., *An Improved Engineering-Economic Model of Residential Energy Use*, Oak Ridge National Laboratory, ORNL/CON-8, April 1977.

2. E. Hirst and J. Carney, *Residential Energy Use to the Year 2000: Conservation and Economics*, Oak Ridge National Laboratory, ORNL/CON-13, September 1977.

3. 94th Congress, *Energy Policy and Conservation Act*, PL 94-163, December 22, 1975.

4. 94th Congress, *Energy Conservation and Production Act*, PL 94-385, August 14, 1976.

5. The White House, *The President's Energy Program*, April 20, 1977. Also Executive Office of the President, *The National Energy Plan*, April 29, 1977.

6. Central Intelligence Agency, *The International Energy Situation: Outlook to 1985*, ER 77-10240U, April 1977. Also, J. D. Pearson, personal communication, Federal Energy Administration, May 1977.

7. C. L. Wilson, *Energy: Global Prospects 1985-2000*, Report of the Workshop on Alternative Energy Strategies, McGraw-Hill, New York, NY, 1977.

8. Hittman Associates, Inc., draft option papers on "Building Insulation Technology," HIT-689; "Heat Pump Technology," HIT-690; "Appliances Technology," HIT-691; and "Lighting Technology," HIT-692, March 30, 1977.

9. Hittman Associates, Inc., *Development of Residential Buildings Energy Conservation Research, Development, and Demonstration Strategies*, HIT-681, August 1977.

10. Energy and Environmental Analysis, Inc., *Summary Results of Threshold and Risk Analysis Data Audit*, June 1977.

11. Gordian Associates, Inc., *Heat Pump Technology*, CONS/2127-d, draft, July 1977.

12. Energy Research and Development Administration, *Buildings and Community Systems Program Approval Document: FY 1978*, August 1977.

13. Division of Buildings and Community Systems, *Consumer Products and Technology Branch Program Plan*, Energy Research and Development Administration, ERDA 77-81, September 1977.

14. Bureau of the Census, "Projections of the Population of the United States: 1975-2050," *Current Population Reports*, Series P-25, No. 601, U.S. Department of Commerce, October 1975.

15. J. Carlin, personal communication, Federal Energy Administration, May 1977.

16. S. Carhart, personal communication, Brookhaven National Laboratory, March 4, 1977.

17. E. Hirst and J. Kurish, *Residential Energy Use to the Year 2000: A Regional Analysis*, ORNL/CON-17, November 1977.

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