EFFICIENT RESIDENTIAL APPLIANCES AND SPACE CONDITIONING EQUIPMENT: CURRENT SAVINGS POTENTIAL, COST EFFECTIVENESS AND RESEARCH NEEDS

Howard S. Geller
American Council for an Energy-Efficient Economy

ABSTRACT

Appliances, air conditioners and water heaters (hereafter refered to simply as appliances) account for about 50% of residential energy consumption in the U.S. on a primary basis. In housing with a high level of thermal integrity, appliances present a much larger fraction of the total energy demand. However, there are products commercially available which can greatly reduce appliance energy consumption. For nearly all appliance types, there are now models which are at least 50% more efficient than the typical model produced in recent years. These products are presented and described in the paper.

Regarding cost, the top-rated products do have a greater first cost than models of average efficiency. The percentage price increase varies for different product types. When life cycle cost is considered, it is shown that highly efficient appliances turn out to make attractive investments for typical consumers. It is estimated that the the rate of return on the extra first cost associated with the top-rated models varies from 9-52%/yr in real terms.

There are a variety of research activities that could lead to further improvements in the efficiency and performance of appliances. Continued research, development and demonstration of advanced refrigerators, air conditioners, water heaters, and other products should be carried out, and some of the more urgent and promising areas for R&D are mentioned in the paper. The development of efficient air conditioners with high latent cooling capacities is one specific need. Also important is the collection of additional field performance data on individual appliances as well as "whole house effects". Finally, establishing an appliance testing center could prove useful for analyzing and showcasing state-of-the-art appliances from around the world, and possibly for other activities.

EFFICIENT RESIDENTIAL APPLIANCES AND SPACE CONDITIONING EQUIPMENT: CURRENT SAVINGS POTENTIAL, COST EFFECTIVENESS AND RESEARCH NEEDS

Howard S. Geller
American Council for an Energy-Efficient Economy

Appliances, air conditioners and water heaters (hereafter refered to simply as appliances) account for about 50% of residential energy consumption in the U.S. on a primary basis. In housing with a high level of thermal integrity, appliances present a much larger fraction of the total energy demand. There are a number of basic questions regarding the energy performance of residential appliances: How has the efficiency and energy consumption of appliances changed in recent years? What is the variation in efficiency between different products available to consumers? What is the savings potential from using highly efficient appliances? What is the cost effectiveness of buying highly efficient apppliances? What technological advances are on the horizon? What research activities are necessary to provide even more efficient appliances in the future?

These questions and issues related to the implementation of energy efficient appliances are the theme of a handbook published in 1983. (1) The objective of this paper is to update the handbook with an emphasis on technological concerns and research needs. In the first part of the paper, the trends in the efficiency of new products are reviewed. Then, the highly efficient products that are now commercially available are described, overall savings potential is briefly discussed, and the cost effectiveness of purchasing highly efficient products is examined. Finally, the research needs related to efficient appliance technology are addressed.

TRENDS IN THE EFFICIENCY OF NEW PRODUCTS

Table I shows the available data on the average efficiency of new models produced since 1972. The efficiencies are based on the standardized tests specified by US DOE and conducted mainly by the manufacturers. It is seen that there has been a mixed record of efficiency improvement; for some products there have been substantial gains during certain periods while for other products the documented progress has been limited. This is a consequence of a complicated set of factors including the availability, promotion and acceptance of more efficient models, the nature of purchasers and purchase decisions, and the regulatory and incentive programs used to stimulate the adoption of efficient models.

New furnaces and water heaters showed no gains in average efficiency during the 1970's. Unfortunately (and inexcusably), no data on the efficiency of new water heaters has been collected since 1980.

Efficiency data are finally being obtained again for furnaces beginning with models produced in 1983. The data show gas furnace efficiencies increasing from an average AFUE value of around 63% in the 1970's to nearly 70% in 1983. The improvement was due to the introduction and sales of furnaces with induced or forced draft and the condensation of flue gases beginning in 1981-82. Industry sales data show that condensing units accounted for 7% of total gas furnace sales in 1983. (2) While there were virtually no gas furnaces with AFUE values in excess of 80% in 1980, their market share increased to about 15% as of 1983.

There were major gains in the efficiencies of refrigerators and freezers during the 1970's, with the typical refrigerator produced in 1981 consuming 1190 KWh/yr compared to 1725 KWh/yr in 1972 based on the standardized test procedure. Freezers on the average were down from 1460 KWh/yr to around 840 KWh/yr in 1981. It has been argued that minimum efficiency standards enacted in California and the expectation of federal standards induced these changes. (3) However, manufacturers claim they are responding to the demand for more efficient products which in turn is a result of rising electricity prices. (4)

Since 1981, there have been very modest improvements in the efficiency of new refrigerators and freezers. The average annual increase in the efficiency of new refrigerators was only 2.4% per year from 1981-83, compared to 7.1% per year from 1978-81. Recent improvements in the efficiency of new freezers have been even more gradual. These slowdowns are in spite of a 12.4% real increase in the average electricity price paid by residential consumers from 1980 to 1983, compared to an average real price increase of only 3.0% for 1977-80. (5)

Clearly, market forces are not sufficient for explaining the complexities of consumer product efficiency. The gains in the efficiency of refrigerators in the 1970's were a result of relatively simple and inexpensive design changes such as switching to polyurethane insulation and using a somewhat more efficient motor-compressor. While many additional improvements are possible and cost effective (see below), some are much more complicated. Furthermore, refrigerator and freezer manufacturers have been facing no pressures from minimum efficiency standards in recent years. (6)

For residential air conditioners, there have been gradual improvements in average efficiency over the past 12 years. Air conditioners are also the product most affected by regulatory and incentive programs. Most states have minimum efficiency requirements for air conditioners in their building codes, and some major states such as California, New York and Florida regulate the efficiency f all models sold within their borders. In addition, many utilities in hotter parts of the country are offering rebate incentives to their customers if they purchase more efficient air conditioners.

The detailed shipment-efficiency data distributed annually by the central air conditioner (CAC) industry association suggest that these programs may be a major factor behind recent efficiency advances. (7) In 1981, 49% of CAC shipments were in the SEER range of 6.5-7.9 and 36% were in the range of 8.0-8.9. In 1982, only 24% of shipments were in the former range while 62% were in the latter. Furthermore, shipments of highly efficient models (SEERs in excess of 10.0) dropped from 2.7% of total shipments in 1981 to 2.3% of the total in 1982. Hence, the rise in average efficiency from 1981 to 1982 was due to a shift in sales in "the middle of the pack" around the efficiency of SEER = 8.0. In fact, this point is where standards are typically set and where models generally began to qualify for rebates.

ENERGY SAVINGS POTENTIAL

Table II lists the highly efficient top-rated models now available and their efficiencies in comparison with typical models sold in 1980. It is seen that there are major savings opportunities in all areas.

As mentioned previously, the highly efficient furnaces include forced or induced draft and the condensing of flue gases. There are now about eight companies selling condensing furnaces in the U.S.

The top-rated gas water heater shown in Table II, the Amana EGWH, involves coupling a hot water tank to the Amana condensing furnace. This eliminates the substantial flue losses which occur in a conventional water heater and provides the high heat transfer efficiency of the furnace for water heating. Of course, it is necessary to have the condensing furnace in order to obtain the high water heating efficiency. Therefore, the most efficient stand-alone gas-fired water heater is also included in Table 2. This model (and a few other water heaters recently introduced) utilize sealed combustion and direct venting. Also, the development of pulse combustion, condensing gas water heaters is proceeding. A prototype unit with an overall efficiency of 83% has already been produced. (8)

For electric water heating, heat pump water heaters (HPWHs) reduce electricity consumption by approximately 50% relative to conventional resistance models. (9) The top-rated HPWH listed in the table also features a plate condenser built into the water storage tank and thicker than average foam insulation. Although HPWHs have been widely produced for a few years, their adoption is still rather limited.

For air conditioners and space conditioning heat pumps, large improvements in overall efficiency have been achieved through the use of larger condenser and evaporator coils, more efficient motors, the use of oversized, derated compressors and rotary-type compressors, and improved controls. In addition, some of the highly efficient models are beginning to utilize two-speed compressors, dual compressors or continuous speed modulation. This provides a much better matching of air conditioner output to the load, thereby reducing cycling losses.

Improved refrigerators and freezers have been developed through a variety of design changes, including the use of better insulation and more efficient motors and compressors. Until early 1984, the most efficient two-door top mount refrigerator-freezer with automatic defrost, the Amana model included in Table 2, consumed 870 KWh/yr based on the DOE test. This model has separate evaporator coils for the refrigerator and freezer boxes which greatly cuts down on frost buildup and the operation of defrost heaters. However, the model was taken out of production because the manufacturer introduced a new standard line of refrigerators which consume only 10-15% more electricity than the TSC-18E. According to the manufacturer, the extra first cost for the twin evaporator model ($50-100 at the retail level) could not be justified for only about 100 KWh/yr of electricity savings. (10)

Although the highly efficient Amana model is no longer produced, there are other commercial models close to its efficiency. In particular, Whirlpool is producing a 17 cubic foot refrigerator-freezer which consumes about 880 KWh/yr (this model is also sold by Sears).

Higher refrigerator efficiencies have been obtained using a prototype motor-compressor developed in the late 1970's by a company which is now part of White-Westinghouse. This unit was placed in ordinary refrigerators for a series of field tests in 1981-82. The results were impressive - the average electricity consumption was 760 KWh/yr (a 27% savings) with 18 cubic foot two-door models. (11) Also, an attempt is being made to combine this prototype motor-compressor with the twin evaporator Amana box. This should lead to an electricity consumption of only 650 KWh/yr. So far, however, the improved motor-compressor has not found its way into commercial models.

As expected, widespread adoption of highly efficient appliance technologies could have a major impact on aggregate energy demand. A recent study of this potential in single family housing found that even with increasing appliance saturation and an expanding housing stock, appliance energy consumption could drop 28% in absolute terms from 1980 to 2000 if today's best commercial technologies are fully implemented. (12) Of course, the savings potential rises as even more efficient appliance technologies reach the marketplace in the future.

The effect of increasing appliance efficiency on space conditioning requirements is pertinent to the discussion of the savings potential with efficient appliances. Some building simulation studies have begun to address this issue. (13) These studies show that reducing internal thermal gains through the use of more efficient appliances will still result in substantial overall energy savin s. This is due to some thermal gains occuring in unconditioned space, space heating being required only part of the year, and the losses associated with electricity generation. Of course, the overall benefit from the use of more efficient appliances is site specific and will increase as space cooling grows in importance.

COST EFFECTIVENESS

Highly efficient appliances generally cost more than models of average efficiency. Table III shows the estimated installed cost for the top-rated products now on the market along with the increase in cost relative to models of average efficiency. The costs were obtained primarily from dealers and contractors in the metropolitan Washington, D.C. area. The extra costs may not necessarily reflect the increased production cost, but rather what the manufacturers feel the more efficient products can command in the marketplace.

It is seen in Table III that the top-rated heat pump water heater has a first cost about four times that of an ordinary resistance water heater. For the highly efficient furnaces and CAC systems, the first cost increases about 70%. On the other hand, the highly efficient refrigerators and freezers are only about 10% more expensive than their counterparts of average efficiency.

Table IV shows the cost effectiveness of buying the top-rated models relative to those of average efficiency assuming national average energy prices and demand conditions. The simple payback period on the additional first cost ranges from 2.0 to 8.6 years. On the average, the payback period is less than half of the assumed lifetime.

The rate of rate of return on the extra first cost, realized through the reduced operating cost, ranges from 9%/yr to 52%/yr. These returns are above inflation and tax-free. Hence, when viewed in terms of life cycle costs, the top-rated products are very attractive for typical consumers. The reasons why these products do not dominate the market given their cost effectiveness are discussed elsewhere. (14)

AREAS FOR FURTHER R&D

In the past, research funded through US DOE, GRI, EPRI and other organizations has directly led to the development and initial commercialization of innovative, highly efficient appliance technologies. This includes a number of the products mentioned above such as the condensing furnace, heat pump water heater, and the advanced refrigerator previously made by Amana.

Further R&D work should also prove to be valuable for a variety of reasons. First, a number of the advanced technologies that are now under development look very promising. Included here are more advanced refrigerators and gas-fired water heaters. Second, the economic evaluation shows that none of the currently available top-rated products are at the cost effective limit. Third, the U.S. appliance industries are not yet confronting any technological limits. This fact is confirmed by the advances occuring at both the commercial and experimental levels in Europe and Japan, as well as the progress being made in the U.S. (15)

Both a continuation of current R&D projects and new efforts are warranted, including work in the following areas:

<u>Refrigerators and freezers</u>

- use of dual evaporators and compressors in refrigerator-freezers;
- use of new refrigerant mixtures;
- more efficient motors and compressors;
- reducing thermal gains through the box.

Freezers have so far received very limited attention among the publicized efforts to develop energy efficient appliances. Furthermore, the top-rated chest freezers currently available in the U.S. are produced by a small company in Canada. Clearly, there is a need for developing highly efficient freezers within the U.S.

Air conditioning equipment

As the thermal integrity of housing in hotter climates is improved, the ratio of latent to sensible cooling load increases. (16) However, some of the more energy-efficient air conditioners have a reduced latent cooling capacity due to the use of higher evaporator temperatures. Using dehumidifiers for latent cooling is not desirable due to their low efficiency. Therefore, efforts should be made to develop efficient air conditioners and heat pumps with high latent cooling capacities.

Water heaters

The development of fuel-fired water heaters with flue gas condensation should continue. Another interesting possibility is the water and/or space heating heat pump that operates off a building's exhaust air stream. This technology has been pioneered in Sweden. (17) It requires the use of controlled ventilation, which is desirable for maintaining a high level of indoor air quality.

Laundry equipment

Reducing water consumption in clothes washers through techniques such as front loading could provide significant energy savings. The continued development of detergents that permit cold water washing should also be pursued. Another innovative idea that has been suggested is the development of chemical additives to permit additional water extraction in the washer rinse cycle without excessive clothes wrinkling. (18) This would be of value since mechanical water extraction is much more efficient than the use of a conventional clothes dryer.

Other Areas

Improved controls is a generic area that could lead to reductions in appliance energy consumption. The "smart appliances" of the future could include freezers that automatically defrost when needed, clothes washers that adjust the water level to the load, and stove burners and ovens with preset or automatic termination. Also, variable speed controls for air conditioners and heat pumps look promising.

Much of the analysis conducted on appliances is based on the laboratory test ratings. Although some utilities and other organizations have measured the energy consumption of appliances in actual use, additional field performance data is needed to check the validity of the test ratings as well as to assess the real impacts of efficient appliances and appliance programs. Also, it would be useful to evaluate how changes in user behavior and product age affect actual appliance energy consumption. Finally, "whole house" field studies should be carried out to study issues such as the interaction between appliance efficiency and space conditioning requirements.

It appears that some Japanese refrigerators are more efficient than the top American models. (19) Also, a variety of highly efficient products are being produced in Europe. However, drawing conclusions in this area is complicated by the different standardized test procedures that are used for testing appliances in the U.S., Europe and Japan. For example, refrigerators are tested in a 32°C hot room with no door openings in the U.S. and at both 30 and 15°C with door openings in Japan. This makes the comparison of products from different countries highly uncertain.

In order to accurately compare appliance technologies from around the world and to provide the information to a broad audience, an international appliance testing center could be established. In addition to aquiring and testing existing equipment, the appliance center could engage in other activities like product development and the collection of field performance data.

REFERENCES

1. H.S. Geller, "Energy Efficient Appliances", American Council for an Energy-Efficient Economy and Energy Conservation Coalition, Washington, DC, June 1983.

2. Information provided by the Gas Appliance Manufacturers Association, Arlington, VA, July 1984.

3. D.B. Goldstein, "Refrigerator Reform: Guidelines for Energy Gluttons", Technology Review, Feb./March 1983.

4. See comments presented by the Association of Home Appliance Manufacturers to the U.S. Department of Energy on the proposed rulemaking regarding appliance energy efficiency standards, June 1982.

5. The electricity price data applies to privately owned utilities and was obtained from "Monthly Energy Review", DOE/EIA-0035, Energy Information Administration, U.S. Department of Energy, Washington, D.C. The prices are corrected for inflation using the implicit price deflator for personal consumption expenditures.

6. Besides the failure of the Reagan Administration to adopt meaningful minimum efficiency standards, the California state standards were not inhibiting the sale of any refrigerators being produced nationwide as of 1983. See "California's Appliance Standards: An Historical Review, Analysis, and Recommendations", P400-83-020, California Energy Commission, Sacramento, July 1983.

7. Data collected and distributed by the Air-Conditioning and Refrigeration Institute, Arlington, VA.

8. See W.H. Thrasher, R.J. Kolodgy and J.J. Fuller, "Development of a Space Heater and a Residential Water Heater Based on the Pulse Combustion Principle", paper to be presented at the 1984 ACEEE Summer Study on Energy Efficient Buildings, Santa Cruz, CA, Aug. 1984.

9. For a compilation of data on the electricity savings with heat pump water heaters, see A. Usibelli, "Monitored Energy Use of Residential Water Heaters", paper to be

presented at the 1984 ACEEE Summer Study on Energy Efficient Buildings, Santa Cruz, CA, Aug. 1984.

10. Personal communication with Mr. Ray Bowman, Amana Refrigeration, Inc., Amana, IA, March 1984.

11. M.G. Middleton and R.S. Sauber, "Research and Development of Energy-Efficient Appliance Motor-Compressors, Vol. IV - Production Demonstration and Field Test", ORNL/Sub/78-7229/4, report prepared by Kelvinator Compressor Co. for Oak Ridge National Laboratory, Oak Ridge, TN, Sept. 1983.

12. R.H. Williams, G.S. Dutt and H.S. Geller, "Future Energy Savings in U.S. Housing", Annual Review of Energy, Vol. 8, 1983, pp. 269-332.

13. See L. Palmiter and M. Kennedy, "Annual Thermal Utility of Internal Gains", paper presented at the 8th National Passive Solar Conference, American Solar Energy Society, Santa Fe, NM, 1983. Also, an unpublished study on this topic has been carried out by the Residential Analysis Group, Energy Analysis Program, Lawrence Berkeley Laboratory, Berkeley, CA, 1981.

14. See Reference 1.

15. For a description of many of the highly efficient appliances under development in Denmark, see J.S. Norgard, "Same Comfort in Buildings with One Third of Present Electricity Consumption", paper to be presented at the 1984 ACEEE Summer Study on Energy Efficient Buildings, Santa Cruz, CA, Aug. 1984.

16. P. Fairey, "Superinsulation and Cooling", Florida Solar Energy Center, Cape Canaveral, FL, paper presented at the 1984 Superinsulation Forum, Rochester, MN, April 1984.

17. L. Schipper, "Energy Efficient Housing in Sweden", report to be published by the American Council for an Energy-Efficient Economy and the German Marshall Fund, Washington, DC, 1984.

18. W.P. Levins, "Energy and the Laundry Process", ORNL/CON-41, Oak Ridge National Laboratory, Oak Ridge, TN, April 1980.

19. Information on the energy efficient appliances produced in Japan has been compiled by Haruki Tsuchiya, Research Institute for Systems Technologies, Tokyo, Also, see References 1 and 3.

Table I. Trends in the efficiency of new products.

Product	Efficiency Parameter	1972	1978	Efficiency (a) 1980	1981	1982	1983
Gas furnace	% seasonal efficiency (b)	63.2(e)	63.6	63.3(f)	--	--	69.6
Gas water heater	% overall efficiency (b)	47.4	48.2	47.9(f)	--	--	--
Electric water heater	% overall efficiency (b)	79.8	80.7	78.3(f)	--	--	--
Central air conditioner	SEER (c)	6.66	6.99	7.60	7.83	8.31	8.43
Room air conditioner	EER (c)	6.22	6.75	7.02	7.06	7.14	7.29
Refrigerator/ freezer	energy factor (d)	3.84	4.96	5.59	6.09	6.12	6.39
Freezer	energy factor (d)	7.29	9.92	10.85	11.27	11.28	11.36

(a) Average efficiencies are weighted by manufacturers' shipments. Data provided by the industry associations AHAM, GAMA and ARI. Also, see "Consumer Products Efficiency Standards Economic Analysis Document", DOE/CE-0029, U.S. Department of Energy, March 1982, p. 31.

(b) The seasonal efficiency for gas furnaces is the AFUE value and the overall efficiency for water heaters is the service efficiency as specified by the US DOE test procedures.

(c) EER is the energy efficiency ratio in terms of BTU/hr of cooling output divided by watts of electrical power input. The SEER for central air conditioners is a seasonal energy efficiency ratio as specified by the US DOE test procedure (see Federal Register, Vol. 44 p. 76700, Dec. 27, 1979).

(d) Energy factor is the corrected volume divided by daily electricity consumption where corrected volume is the refrigerated space plus 1.63 times the freezer space for refrigerator/freezers and 1.73 times the freezer space for freezers.

(e) 1975 rather than 1972.

(f) These values are estimates made by manufacturers in 1979.

Table II. Comparison of highly efficient and typical models for major products.

Product	Efficiency Parameter	Efficiency of Typical Model Sold in 1980	Highly Efficient Model(s) Available in 1984	Efficiency of Top Models Available in 1983/84
Gas furnace	seasonal efficiency	0.63	Condensing furnaces sold by Lennox, Amana, Sears Heil, Whirlpool, et al.	0.94-0.96
Gas water heater	overall efficiency	0.48	Amana EGWH State "Turbo Super-saver"	0.83 0.64
Electric heat pump	heating COP	1.7	Rheem/Ruud RPGA and UPGA series	2.6
Electric water heater	overall COP	0.78	DEC Int. "Therma-Stor" heat pump water heater	2.2
Central air conditioner	SEER	7.6	Lennox Landmark IV Series, HS-14	14.0
Room air conditioner	EER	7.0	Friedrich SM10G10	11.5
Top mount refrigerator/freezer with automatic defrost (16-18 ft^3)	Energy factor	5.6	Amana TSC-18E Kenmore 63771 Whirlpool ET17HKXM	8.7 8.4 8.4
Chest freezer with manual defrost (14-16 ft^3)	Energy factor	10.8	W.C. Wood's E420	18.7
Upright freezer with manual defrost (15-16 ft^3)	Energy factor	10.8	Kenmore 241580, 241540	13.1

Table III. First costs for highly efficient residential products (a).

Product	Capacity (useful output)	Installed Cost (1984 $)	Increased First Cost Compared to Standard Model (b) (1984 $)
Lennox pulsed combustion gas furnace (c)	2,000 BTU/hr	2,300	1,000
Rheem/Ruud RPGA and UPGA series heat pump	42,000 BTU/hr	3,800	650
DEC International Therma-stor heat pump water heater	74 gal/hr	1,600	1,200
Amana EGWH gas water heater	107 gal/hr	760	350
State Industries Turbo Super-saver gas water heater	58 gal/hr	520	110
Lennox Landmark IV central AC system	39,000 BTU/hr	2,500	1,000
Friedrich SM10G10 room air conditioner	10,000 BTU/hr	730	130
Amana TSC-18E refrigerator/freezer (d)	18 cubic feet	900	100
Kenmore 63771 refrigerator/freezer	17 cubic feet	720	60

(a) Cost data obtained from dealers and contractors in the Washington D.C. area.

(b) The cost difference is relative to a standard efficiency model made by the same manufacturer.

(c) One example of a highly efficient condensing furnace.

(d) Model no longer in production, may still be available to consumers in 1984.

Table IV. Cost effectiveness of the additional first cost for highly efficient products (a)

	Simple Payback Period (yrs)	Real Return on Additional Investment (%/yr)
Lennox pulsed combustion gas furnace	8.4	15
Rheem/Ruud RPGA and UPGA heat pump	3.6	27
DEC International heat pump water heater	6.7	12
Amana EGWH gas water heater	6.2	17
State Industries gas water heater	3.3	35
Lennox Landmark IV central air conditioner	6.6	12
Friedrich SM10G10 room air conditioner	8.6	9
Kenmore 63771 refrigerator/freezer	2.0	52

(a) Based on a first year electricity price of $0.072/KWh and a 1%/yr electricity price escalation rate; $6.00/MBTU first year gas price and a 4%/yr gas price escalation rate. The first year energy prices are 1983 national averages. For demand dependent end-uses (space heating and cooling, hot water heating), the demand for a typical U.S. household is assumed. See Table III for product cost assumptions.