Energy Efficient Appliances: 1986 Update

Howard Geller, American Council for an Energy-Efficient Economy

ABSTRACT

This paper reviews the latest developments in energy efficient refrigerators, gas furnaces, water heaters, air conditioners, cooking equipment, and clothes dryers. Both newly commercialized and prototype technologies are covered, including new energy-efficient refrigerators built in Europe and the U.S., advanced heat pump and gas-fired water heaters, gas-fired space heating equipment, air conditioners, heat pump and microwave clothes dryers, and advanced gas stove burners. The performance, energy savings potential, cost-effectiveness, and status of these technologies are examined. Marketing issues are also discussed.

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In previous reports [1,2,3], the author has described and analyzed state-of-the-art developments in energy-efficient appliances. Table I shows the status of U.S. appliances with respect to energy performance. The end-uses included in the table account for about 63% of residential energy consumption. For a number of product categories, today's best available technologies are at least twice as efficient as typical models in the housing stock. Residential energy use per household, which dropped 18% between 1973 and 1984, will continue to fall as the current generation of technologies are absorbed into the equipment stock.

Table I also shows estimates of the energy use of advanced appliance technologies that could become available during the next decade. Progress towards these greater levels of efficiency is occurring throughout the world. This paper reviews energy-efficient appliances commercialized during 1985-86, promising prototypes, and technologies still under development. The issues addressed include savings potential, cost effectiveness, status, and marketing concerns.

REFRIGERATORS

The most efficient mass-produced two-door refrigerator-freezer (R/F) with automatic defrost made in the U.S. in 1986 is a 17.2 cubic foot model that consumes 750 kWh/yr according to the standard test procedure. This model, the Whirlpool ET17HK1M, features an improved motor-compressor (made in Brazil), more efficient fan motors, and 1.5-2.5 inches of foam insulation. It consumes 50-65% less electricity than standard R/Fs built in the U.S. 10-15 years ago.

Based on inquiries with dealers in the Washington, DC area, the top-rated Whirlpool model has an extra first cost of about $60 and saves 330 kWh/yr compared to a standard R/F from the same manufacturer. The top-rated model has a 2.3 year simple payback period and a 45% internal rate of return at the 1985 national average electricity price of $0.078/kWh (see Table II) [4].

Energy-efficient refrigerators with more radical modifications are under development. A prototype 18 cubic foot R/F constructed in Denmark in 1985-86 includes 2.6-3.4 inches of foam insulation, advanced compressors, electronic controls, and separate refrigeration systems for each compartment (i.e., two motor-compressors and separate heat exchangers in the refrigerator and freezer boxes) [5]. It is estimated that this model will consume about 480 kWh/yr using the U.S. test procedure [5]. Testing was underway in mid-1986.

Use of separate refrigeration systems provides substantial efficiency gains and also results in higher humidity levels and less dehydration of food in the refrigerator compartment. Dual refrigeration systems are already included in some European R/Fs [6].

Japanese manufacturers are continuing to improve the efficiency of their refrigerators through use of improved insulation, more efficient refrigeration systems, and electronic controls. The current generation of energy-efficient Japanese R/Fs, 400-430 liters (14-15 cubic feet) -- large by Japanese standards but small by U.S. standards -- consume 430-460 kWh/yr according to the Japanese test procedure [7]. However, the Japanese test is less stringent than that in the U.S. Limited test data indicate a 30-70% increase in electricity use with the U.S. test [8]. More extensive testing of Japanese models in the U.S. in the near future should clear up uncertainties regarding their performance relative to American models [9].

Japanese manufacturers are moving ahead in marketing larger refrigerators in the U.S. Sanyo, now selling R/Fs in the U.S. on a limited basis, has acquired a plant in Indiana in order to manufacture larger R/Fs and other appliances. Japanese companies including Panasonic and Mitsubishi are marketing room air conditioners in the U.S. and they may follow suit with other appliances such as refrigerators.

Evacuated panel insulation is one of the more promising technologies for improving refrigerator performance in the future. Evacuated panels, discussed in detail in another paper in this proceedings [10], could be a very cost-effective means of providing a high thermal resistance in a relatively small volume (R-10 or more per inch of thickness). However, the durability of evacuated panels is still a major concern.

GAS FURNACES

Beginning around 1982, highly efficient condensing gas furnaces became available. These furnaces have a power or pulse combustion burner and a heat exchanger that permits cooling of the flue gases to the point where water vapor condenses out. The overall efficiency, known as the annual fuel utilization efficiency (AFUE), is in excess of 90%. Field studies show a typical fuel savings of about 30% compared to standard furnaces of a decade ago [11].

By 1985-86, virtually all major furnace manufacturers offered condensing furnace models. Over 220,000 condensing furnaces were produced in the U.S. in 1985, 12% of all gas furnaces produced that year [12]. Production and sales of condensing furnaces nearly doubled between 1983 and 1985.

Price data from the Washington, DC area indicate that condensing furnaces typically cost around $2500, about double that of a standard furnace with electric ignition [13]. It does not appear that the first cost of condensing furnaces is falling even though the number of models and sales has grown rapidly. Even with the high first cost premium, condensing furnaces are economical as long as the space heating load is reasonably high (see Table II).

Efforts are underway to develop gas-fired heat pumps based on absorption cycle and heat-engine driven concepts. The Gas Research Institute has set performance targets including a heating COP of 1.7-2.0 and a cooling COP of 1.0-1.1 [14]. Commercialization by 1990 is hoped for, but improvements in efficiency, cost, and durability must still be made [14].

ELECTRIC WATER HEATERS

Ordinary heat pump water heaters (HPWHs) consume about 50% less electricity than standard electric resistance water heaters. They typically have a simple payback period of 3-6 years depending on hot water consumption, equipment cost, and electricity price [15]. One manufacturer (DEC International, Inc.) makes HPWHs that are considerably more efficient than other models [1].

DEC International has developed an advanced HPWH that includes an improved plate heat exchanger and thicker insulation. With an in-service energy factor (COP) rating including standby losses of about 3.0, it consumes about 15% less electricity than their current models [16]. For comparison, electric resistance water heaters have energy factor ratings of 0.75-0.95. The advanced DEC International model should be on the market in the near future [16].

Given the typical hot water demand of a four-person household (about 60 gallons/day), the advanced DEC International model saves about 350 kWh/yr compared to their current HPWH. The extra first cost for the advanced model is estimated to be $100 [16]. As shown in Table II, the extra first cost is paid back in 3.7 years and it yields a 27% rate of return at the national average residential electricity price.

Conventional HPWHs are not selling well in spite of having been commercially available for over five years. Approximately 12,000 units were sold nationwide in 1985, accounting for only about 0.3% of electric water heater sales [16]. Some producers have withdrawn from the market. Disappointing HPWH sales are attributed to high first cost, lack of information on the part of consumers, limited availability, and the nature of water heater purchases (i.e., a quick replacement done through a plumbing contractor in many instances).

Manufacturers such as E-Tech, Inc., Energy Utilization Systems and DEC International are staying with HPWHs. They have established markets in hotter states such as Florida, Texas, and Hawaii. Also, sales are increasing in California as a result of the new residential building code there. Some utilities have offered large rebates for HPWHs ($300 or more), but this apparently has not had much impact on sales. Utilities and energy officials should continue to search for effective methods for stimulating the adoption of HPWHs since this technology can provide large electricity and cost savings.

There is some interest in HPWHs that operate in conjunction with a mechanical ventilation system in tightly constructed housing. Heat can be removed from exhaust air during the space heating season and from incoming ventilation air during the space cooling season. HPWH-forced ventilation systems are commonly installed in new homes in Scandanavia. It is claimed that electricity consumption for water heating is reduced by about 60% using this heat pump scheme rather than electric resistance heating [17].

The HPWH-forced ventilation systems under development by DEC International are described in a separate paper in this proceedings [18]. Other companies intend to manufacture and/or distribute Scandanavian systems in North America [19]. Consequently, it is likely that HPWH-ventilation systems will be readily available in the U.S. by 1987.

GAS WATER HEATERS

Ordinary gas water heaters contain a pilot light and 0.75-1.5 inches of insulation. Consequently, they are relatively inefficient with only about 50% of the energy input utilized via hot water [3].

Some steps were taken to raise the efficiency of gas-fired water heating in recent years. The best stand-alone models on the market have energy factor (COP) ratings of 0.61-0.64, reducing gas use by about 20% compared to standard models. It is also possible to indirectly heat water via a high-efficiency condensing gas furnace. This provides a service efficiency of 0.8-0.85 [3]. A few condensing furnaces (e.g., models made by Amana and Glowcore) are available with an optional water tank.

A highly efficient prototype gas water heater with pulse combustion and flue gas condensation was developed with support from the Gas Research Institute in 1983-84 [20]. This unit has a recovery efficiency of 0.90, an energy factor rating of 0.83 and an estimated retail cost of $800-900 [21]. The annual savings compared to use of a typical gas water heater would be about 15 MBtu/yr for a family four consuming 60 gal/day of hot water. With the national average gas price of $6.10/MBtu, the payback for the pulse combustion water heater would be around six years and the real rate of return on the extra first cost is 15%.

Plans to field test the pulse combustion water heater were halted when the manufacturer cooperating with the GRI (State Industries) withdrew their support, evidently because they doubted that the product has commercial potential [21]. As a result, GRI is not continuing the project.

Mor-Flo Industries has developed a highly efficient gas water heater with electric ignition, sealed combustion, and flue gas condensation that is intended for both water heating and space heating in relatively tight homes. This integrated appliance, known as the "Polaris", has a recovery efficiency of 0.94 and an energy factor rating for water heating of 0.85-0.90 [22]. Installed costs including a heat exchanger for use with a forced air heat distribution system are estimated to be $2600-3200 [23]. The Polaris unit was undergoing field testing in 1985-86 and is expected to become commercially available in 1987 [22]. Integrating water and space heating make it feasible to add the features necessary for highly efficient gas water heating.

AIR CONDITIONERS

American air conditioner manufacturers increased the energy efficiency of their products during the past decade through the use of larger heat exchangers, more efficient motors and compressors, and in some cases two-speed compressors [3]. However, the efficiency of the top-rated models in the U.S. has improved only slightly since 1983.

Japanese manufacturers are now making air conditioners and heat pumps with electronic variable speed drives in order to provide continuous capacity variation [24]. The Japanese units condition either a single room or multiple rooms using separate outdoor and indoor coils. The multi-zone systems feature individually controlled fan coil units in different rooms, taking advantage of the variable capacity potential.

It is estimated that adding a variable speed drive and continuous capacity variation increases the efficiency of an air conditioner by 15-20% [25]. This is due primarily to the superior performance of the compressor when it is operating in a derated mode. Also, the variable speed drive permits zonal control and better matching of output to particular space conditioning needs, leading to additional energy savings. A simulation study showed that a variable speed heat pump with zonal control in a single family home in Tennessee would use 27% less electricity than a conventional single-speed system [26].

Adding a variable speed drive to an air conditioner is not cheap -- an official from Carrier Corporation estimates the extra first cost would be $200-250/ton initially, with cost reductions once the technology is established and mass-produced [25]. This implies an extra first cost of about $190 for a typical room air conditioner and $650 for a typical central air conditioner, at least initially. It may not be possible to justify the extra first cost on the basis of energy savings alone because of the limited usage of many residential air conditioners. For example, the expected savings with a typical room air conditioner is only 125-150 kWh/yr.

But the variable frequency drive and electronic controls provide other benefits such as quieter operation, more flexible control, and the possibility for adding self-diagnostic features. The Carrier Corporation is developing an integrated space and water heating heat pump with variable speed control in conjunction with EPRI. According to a Carrier official, American manufacturers will produce air conditioners and heat pumps with variable speed drives by 1988 [25].

The dehumidification capacity of highly efficient air conditioners is an area of concern especially in tight housing in humid climates. Raising the evaporator coil temperature increases the efficiency of an AC unit, but it also reduces the latent cooling capability. A heat pipe-assisted AC system was developed to increase the latent-to-sensible cooling ratio in an efficient manner. The heat pipe extracts some heat from incoming air and delivers it to overcooled, dry air. A small company in Florida is now marketing heat pipe-assisted air conditioners [27]. Also, variable speed systems can provide high latent-to-sensible cooling ratios.

In hot, dry climates, direct evaporative coolers have been available for many years. They consume only about 20% of the energy of conventional air conditioners [28]. However, direct evaporative coolers add considerable moisture to indoor air which is unacceptable to some consumers.

Two-stage evaporative coolers were introduced recently by companies in California and the Southwest to overcome the moisture problem. In the first stage, a heat exchanger is used to indirectly cool indoor air without adding moisture. The second stage is an ordinary direct evaporative cooler.

One company (Arvin Industries) offers a 3-ton two-stage evaporative cooler for about $2000, only $200-500 more than the cost for a conventional central AC system (SEER=8.0) [28]. With an estimated savings in electricity consumption for cooling of 50-70%, two-stage evaporative coolers are generally cost-effective for residential applications in hot, dry areas. For example, if the extra first cost is $400 and the savings is just 800 kWh/yr (appropriate for a smaller home with limited central AC use), the simple payback equals 6.4 years and the rate of return on the extra investment is 13%. The payback would be quicker and the rate of return higher with greater AC use.

COOKING EQUIPMENT

The most promising recent advance in cooking technology is the development of an infrared-jet impingement burner for gas stove tops. This burner features a high degree of radiative heat transfer from a ceramic flame holder and the formation of gas jets as the combustion gases pass through holes in a glass plate. The IR-jet burner provides 25-35% fuel savings, greatly reduced NO_x emissions, and higher heat input rates compared to conventional gas burners [29].

The one technical problem that is inhibiting the commercialization of the burner is a poor turndown ratio (i.e., the ratio of maximum to minimum burner output). Designers of the burner at Thermo Electron Corporation thought the problem was resolved, but field testing underway in 1986 showed that it remains. The manufacturer participating in the development of the burner (Caloric Corporation) is optimistic about introducing the burner into their stoves if an acceptable turndown ratio is achieved and commercialization by 1988 is possible [30].

CLOTHES DRYERS

Electric clothes dryers generally are a major electricity demand in households where this appliance is present (see Table I). The main energy saving option currently available is an automatic termination control. This device senses the temperature or moisture level of the exhaust air and turns off the dryer when a certain level is reached. Automatic termination typically reduces dryer energy consumption by up to 10-15% [3].

More radical innovations in clothes dryer technology are "in the pipeline". One approach is to use a heat pump to condense out water in a closed air cycle. A prototype heat pump clothes dryer (HPCD) has been developed by the Nyle Corporation, a company already selling larger-scale heat pump dryers for drying lumber, food products, and other commodities.

Tests of the prototype HPCD show energy savings of 50-60% relative to a conventional electric clothes dryer [31]. In addition, the HPCD has a drain pipe rather than exhaust vent (advantageous in apartment buildings), produces minimal static cling, and results in less wear of clothes. Drying time is about the same as in an ordinary dryer.

It is estimated that the HPCD will have a retail price of $600-700, about twice that of a conventional dryer [32]. Assuming an extra first cost of $300 and a savings of 500 kWh/yr, the simple payback period is 7.7 years and the real rate of return is 13%. The payback is relatively long, but is considerably less than the expected life of a clothes dryer, about 18 years.

The Nyle Corporation is proceeding with commercialization of the HPCD. They have contracted with an appliance manufacturer in Venezuela to make this and other products. Marketing of the HPCD in North America is expected to begin by the end of 1986 [32].

Microwave clothes dryers (MCDs) are also under development. The inventor of one prototype model claims 50% or greater electricity savings, 30-50% time savings, less tumbling, less static, and less wear on clothes than with a conventional electric clothes dryer [33]. There appear to be some problems drying larger loads with high water retention, however [34]. The developer estimates the extra first cost for the MCD will only be $50-100, making this technology potentially very cost-effective. General Electric is seriously examining MCDs and expects they will become commercially available within five years [34].

CONCLUSION

Efforts to increase the energy efficiency of domestic appliances continue in spite of past efficiency improvements and limited public support for or interest in energy conservation at the present time. Recent developments associated with refrigerators, air conditioners, water heaters, gas ranges, and electric clothes dryers should result in a new generation of highly efficient products that will lower residential energy intensity once they are absorbed into the equipment stock.

Many of the recent developments involve radical changes in appliance technology that provide multiple benefits. This is especially important in cases where there is a considerable increase in first cost associated with the new technology. New products that cannot be justified on the basis of energy savings alone may still attractive due to the combination of energy savings, improved quality of service, time savings, health benefits, etc. The existence of multiple benefits helps to convince manufacturers to produce more costly products and helps to sell the products to consumers.

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Table I - SUMMARY OF ENERGY CONSUMPTION AND CONSERVATION POTENTIAL WITH RESIDENTIAL APPLIANCES AND SPACE CONDITIONING EQUIPMENT

Product	Fraction of residential total (%)	1985 Stock UEC[a]	1985 New UEC[b]	1985 Best UEC[c]	Advanced technology for 1990s[d]
		--------(kWh/yr	or	therms/yr)--------	
Refrigerator	7.1	1500	1100	750	200-400
Freezer	2.7	1100	800	500	150-250
Central AC	9.0	3600	2900	1800	900-1200
Room AC	2.3	900	750	500	300-400
El. water heating	8.2	4000	3500	1600	1000-1500
El. range	3.3	800	750	700	400-500
El. clothes dryer	2.7	1000	900	800	250-500
Gas furnace	20.5	730	620	480	300-480
Gas water heating	5.2	270	250	200	100-150
Gas range	1.9	70	50	40	25-30
Gas clothes dryer	0.4	50	40	35	30-35

Unit energy consumption per installation in the 1985 housing stock.

Unit energy consumption for the typical model sold in 1985.

Unit energy consumption for the best available model sold in 1985.

Unit energy consumption possible in new models by the mid-1990s if further cost-effective advances in energy efficiency are made.

Source: American Council for an Energy-Efficient Economy.

Table II - Cost effectiveness of some highly efficient appliances[a]

I. Electrical Equipment

Model	Increased first cost (1985 $)	Annual electr. savings (kWh/yr)	Simple payback period (yrs)	Internal rate of return (%/yr)
Whirlpool ET17HK1M refrigerator/freezer	60	330	2.3	45
Prototype heat pump water heater[b]	100	350	3.7	27
Two-stage evaporative cooler[c]	400	800	6.4	13
Prototype heat pump clothes dryer	300	500	7.7	13

II. Gas-fired Equipment

Model	Increased first cost (1985 $)	Annual gas savings (MBtu/yr)	Simple payback period (yrs)	Internal rate of return (%/yr)
Condensing gas furnace[d]	1200	25	7.9	14
Prototype pulse combustion water heater[b]	550	15	6.0	15

[a] Based on the 1985 national average electricity price of $0.078/KWh, the 1985 average natural gas price of $6.10/MBtu, and a 2%/yr real energy price escalation rate.

[b] Assuming 60 gal/day of hot water consumption which is typical for a family of four.

[c] Assuming a relatively low cooling demand of 12 MBtu/yr as a worst case scenario.

[d] Assuming a typical space heat load of about 60 MBtu/yr.

Source: American Council for an Energy-Efficient Economy.