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Refrigerator Replacement in the Weatherization Program: Putting a Chill on Energy Waste

A special report for the Weatherization Assistance Program

Larry Kinney and Rana Belshe

Summary

Over the past decade, many refrigerator manufacturers have improved the energy efficiency of their products by a factor of three or more. Refrigerators manufactured after 1990 present lower peak loads to the grid and have much higher power factors than those manufactured in previous decades. Accordingly, replacing energy-wasteful refrigerators with new units can be very cost-effective, even when the older, wasteful units are still functional.

A number of weatherization program operators and other organizations have initiated programs to replace old, inefficient units with efficient, new ones. This trend is sure to accelerate, because Department of Energy rule-making recently included refrigerator replacement as an allowable weatherization measure.

Replacement programs can be cost-effective in a number of ways. Several refrigerator programs conducted by weatherization agencies have secured cost-sharing from utility companies, landlords, or both. Bulk purchasing agreements with Maytag, a manufacturer of very efficient refrigerators, allow not-for-profit agencies to buy good-quality new units at a very reasonable price. Further cost-effectiveness can be achieved by using methodologies described in this report to selectively choose which old units to replace and by educating clients in the proper use of their new refrigerators to ensure long-term savings. Suppliers of replacement services who recycle old units can make their profits on recycled materials, so replacement services are typically inexpensive.

Refrigerator replacement programs save electric energy, lower peak demands, improve power quality, and help the environment. They also serve lower-income customers in a most visible and welcome way.

Contents

Refrigerator Replacement in the Weatherization Program: Putting a Chill on Energy Waste

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Introduction

A decade ago, refrigerators in U.S. households consumed an average of 1,220 kilowatt-hours per year (kWh/year). Although many people still have refrigerators that use substantially more energy than that, a revolutionary shift in how refrigerators are designed and manufactured has fundamentally changed the picture.[1] Thanks to the advent of federal energy efficiency standards that raised the efficiency bar in 1990, 1993, and again in July 2001, major U.S. manufacturers have extensively retooled their production lines. In addition, widespread use of robotics in manufacturing operations has slashed labor costs per unit of production and improved quality control.

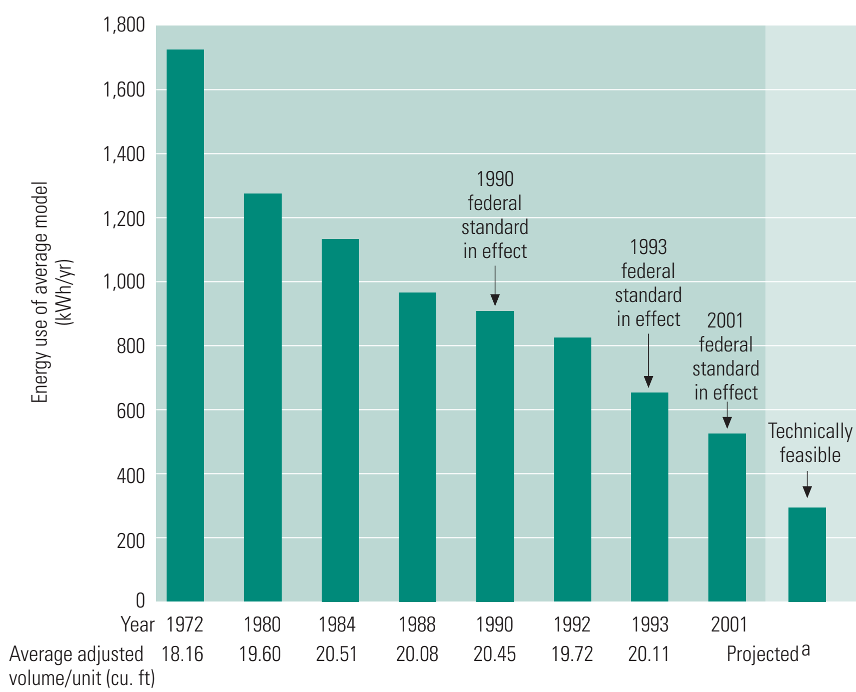
As a result, it is now possible to buy residential refrigerators that perform better, cost less, and have much improved power factors than did units sold in the 1980s. Most important, the best refrigerators consume only about one-third of the energy used by many of the old models. Accordingly, it's often cost-effective to replace old refrigerators—even if they are still working—with energy-efficient new models (**Figure 1**).

A number of weatherization service providers, housing authorities, and utilities are doing just that. Refrigerator replacement programs are usually designed to benefit lower-income customers, and new refrigerators that use a fraction of the energy of the units replaced accomplish this goal quite well.

Of course, taking the plunge to establish a replacement program should be done with care. Like many complex undertakings, details are critical. For example, decisions about which refrigerators to replace are important in achieving good program cost-effectiveness, but making those decisions refrigerator-by-refrigerator has a cost, and mistakes are easy to make. Fortunately, trail-blazing efforts on the part of pioneering refrigerator-replacement program operators make it easier for those who follow to build on their strengths.

Figure 1: Energy consumption of U.S. refrigerators

On average, a refrigerator built after 1993 uses half the energy used by a refrigerator built in 1980. The energy requirements for units built for the 2001 standards are about 750 kWh/yr less than 1980 models.



Note: a. The 2001 energy consumption figure is an E SOURCE projection.

Why New Refrigerators Perform Better Than Old Ones

Back when ice was used to keep food and drinks cool, thick-walled insulation and radiant barriers were used to make ice boxes efficient and practical. When electric refrigerators came along, early models retained the good insulation, and the heat-producing compressors were mounted on top. Over several decades, however, these early refrigerators gave way to slick consumer models designed to maximize sales by increasing food-carrying capacity and integrating a number of "features" that tended to waste energy. Space for insulation was minimized, the compressor was placed below the cooling compartments, defrosting was automated, and ice makers and water coolers that dispense water through the door were installed. Consequently, many of the units sold in the 1980s contained as many as six electric resistance heaters (to warm crispers, butter trays, and the space between doors, for example), and some used 2,000 kilowatt-hours (kWh) per year of energy or even more.

Standards for energy efficiency changed all that. Now, energy-efficient refrigerators include such features as much-improved insulation, enhanced heat exchanger surfaces, more efficient fans and motors, better compressors, "smarter" controls that adapt compressor runs and defrost cycles to instantaneous circumstances, and power factor compensation circuitry. Researchers at the Oak Ridge National Laboratory have designed and tested a 20-cubic-foot (ft^3) prototype unit that uses vacuum panel insulation and most of the above-mentioned features; its measured performance is 340 kWh per year.[2] Some European models use separate compressors for the fresh food and freezer compartments, thereby optimizing the match of cooling energy to instantaneous loads. The result is even better performance.[3] If the near future resembles the near past, there's reason for optimism that that even more energy-efficient refrigerators will be available for the residential market soon.

Pioneering Efforts

A number of weatherization agencies and other organizations have undertaken refrigerator replacement work. These pioneers have found where the potholes tend to form and how to circumnavigate most of them. Most important, their successes in implementing various refrigerator program strategies make it easier for others to follow in their footsteps.

DOE-sponsored weatherization. The Weatherization Assistance Program operated by the Department of Energy (DOE) is the longest-running energy conservation program in the United States. Started in Maine in the winter of 1973 as an effort to air seal and insulate homes of low-income people whose fuel bills had quintupled during that year's oil boycott, the program has matured gracefully. Currently, it is professionally conducted in most areas of the country by local community action agencies and other not-for-profit organizations. Utilities all over the country have made use of the weatherization network to deliver conservation services to their low-income customers.

Traditionally, most weatherization work has concentrated on measures for saving energy used for space conditioning, but refrigerator replacements and other electricity-saving measures are now allowable by the DOE.[4] Anticipating this change, a number of refrigerator replacement pilot projects involving weatherization programs and utilities have been conducted.

For example, in June 1995, the New York State Weatherization Assistance Program requested a waiver from DOE headquarters to conduct pilot refrigerator replacement projects. Principal points made in the request for waiver were as follows:

- The cost of electricity on a Btu/dollars basis is 5 to 10 times the cost of natural gas or fuel oil, the most commonly used fuels for space heating.
- Many tenants whose space and hot-water heating costs are included in their rent must nonetheless pay directly for their electricity costs. Refrigerators, which operate throughout the year, are frequently the largest single consumer of electricity in an apartment.

- Many people, especially lower-income people, have old refrigerators that are quite wasteful of electricity.
- Energy-efficient refrigerators are becoming widely available at attractive costs, particularly if they are bought in bulk.
- Weatherization technicians routinely perform energy audits that could readily be modified to accommodate refrigerator inspection and (when necessary) measurement of energy consumption.
- Good electronic devices for measuring the energy performance of refrigerators are becoming available.
- There is a high probability that refrigerator replacements will yield very favorable ratios of benefits to costs.[5]

The DOE approved the waiver request on the condition that cofunding be secured from landlords or utilities and that cost-benefit analyses be conducted.

Shortly thereafter, the local weatherization program in Geneseo, New York, teamed up with the Rochester Gas & Electric Corp. (RG&E) to replace refrigerators in an 80-unit apartment complex. The agency measured consumption on a sample of refrigerators and determined that 54 refrigerators could be replaced cost-effectively (**Figure 2**). A 14-ft^3 model manufactured by Whirlpool was installed, and the savings achieved averaged 69 percent (946 kWh/year) for a very favorable savings-to-investment ratio (SIR) of 2.60. This means that $2.60 is recovered through lower utility bills for each $1.00 invested.

In New York City, a number of local weatherization agencies are involved in refrigerator replacements in which an approximately equal mix of weatherization money, landlord donations, and funds from Consolidated Edison (Con Ed) are combined to change out refrigerators in buildings with mostly low-income occupants. The result of evaluations of the first 636 of these replacements showed annual savings of 48 percent (455 kWh) with an SIR of 1.81.[6]

Figure 2: Delivery of a new refrigerator in Geneseo, New York

Delivery of refrigerators to suburban apartment complexes is much easier than dealing with large multi-family buildings in New York City.

Source: Synertech Systems Corp.; photo by Larry Kinney

The more favorable SIR achieved by the RG&E project (2.6 as opposed to 1.81) reflects the fact that only units with relatively high consumption were replaced under the RG&E project. **Table 1** (next page) shows statistics from these successful collaborations between weatherization programs and utilities.

Adding the refrigerator replacement arrow to the weatherization program's quiver of conservation measures should benefit all parties. "Now that we have the regulations in place to allow for refrigerator replacements," says Gail McKinley, national director of the Weatherization Program, "we're looking forward to providing an even broader range of cost-effective energy savings measures for the people served by our program."[7]

HUD housing. The largest refrigerator replacement program in the U.S. is under way in New York City. Over an eight-year period, the New York Power Authority (NYPA) is systematically replacing virtually all of the refrigerators in the 180,000 apartments operated by the New York City Housing Authority (NYCHA). Under a deal struck with NYCHA and the U.S. Department of Housing and Urban Development (HUD), which pays the electric bills in NYCHA apartments,

Table 1: Results of pilot weatherization program and utility refrigerator program collaborations

Results in this table are based on the assumptions that the cost of electricity for residential customers of RG&E, 12.4¢ per kWh, and of Con Ed, 16.1¢ per kWh, will track inflation; the lifetime of the new units will be 20 years; and the discount factor (to account for a present full payment whose stream of benefits will occur over time) is 4.8 percent.

Utility	Energy consumption of average replaced unit (kWh/yr)	Energy consumption of average new unit (kWh/yr)	Annual energy savings (kWh/yr)	Energy savings (%)	Annual savings ($)	Cost per unit ($)	SIR
RG&E	1,364	418	946	69.4	117.31	564	2.6
Con Ed	938	483	455	48.5	73.19	504	1.81

Note: SIR greater than 1 is considered cost-effective. Project costs include administrative overhead as well as costs for the new units, demanufacturing, and transportation.

NYPA is supplying the new refrigerators and managing the replacement and recycling operations.

HUD's electricity bills are lowered, and NYCHA has happier tenants owing to new frost-free refrigerators that, in most cases, are larger than the inefficient units they replace. NYPA not only is reimbursed for its costs but also has solidified its relationship with one of its largest customers (NYCHA owns 2,900 buildings in New York City). An important manifestation of this increased goodwill is an agreement that NYCHA will retain NYPA as its sole supplier of electricity for 15 years. In this volatile age of restructuring, such an agreement is something of a security blanket for both parties.[8]

On a typical working day, an 18-wheeler bearing 90 new 15-ft^3 refrigerators from Maytag's factory in Galesburg, Illinois, shows up by seven o'clock in the morning at the appointed apartment complex in New York City. While drivers begin offloading and uncrating new units, workers for NYPA's contractor, CSG Services Inc., an affiliate of the Conservation Services Group (CSG), begin removing old units. They work from the top story down, replacing old refrigerators with new ones (**Figure 3**). By early afternoon, the new units are keeping food cool, and the elevators in the apartment building are freed up for the return home of hungry school children.

A truckload of old refrigerators and packing material is then on its way to Syracuse, where CSG maintains a major recycling facility, and Maytag trucks are headed back to the factory to load up for the next day's work (**Figure 4**). More than 450 refrigerators are replaced in a typical working week. About 20 percent of the old refrigerators that appear to be in good condition are not recycled immediately. Instead, they are retained in NYCHA storage facilities to serve as temporary

Figure 3: New refrigerator installation

Refrigerators are often installed immediately next to stoves. The stoves are sometimes used for supplemental heat in NYCHA apartments, which lowers both indoor air quality and refrigerator efficiency.

Source: Synertech Systems Corp.; photo by Larry Kinney replacement units in apartments that have not yet been served by the replacement program.

Virtually all refrigerators in NYCHA apartments are replaced with new units. This "replace 'em all" strategy was a policy decision driven by the need to streamline program operations and to treat all tenants equitably. The reasoning behind the decision was that, although the replacement of some refrigerators would not be cost-effective, the vast majority of replacements would be, thereby making up for the others.

As of mid-2001, the New York City program is into the sixth year of operation. "New York City isn't a very easy place to pull off this kind of program," reports Dennis Flack, CSG's New York State director of operations. "But if we've figured out how to do it there, we can do it anywhere," he maintains.[9] In the first year of the program, 20,000 refrigerators were installed and only one was stolen.

The program has been carefully evaluated using field and test chamber measurements of both old and new refrigerators. In 1999, it was estimated that the New York project achieved 587 kWh/year in energy savings where the average refrigerator removed was 12.9 years old, had a volume of 13.1 ft^3, and an energy use of 1,013 kWh/year. In addition, a demand savings of 74 watts per refrigerator was achieved.[10]

Figure 4: Out with the old

Many more old units than new units can be loaded into an 18-wheeler. The trip to the recycling facility is the last one for the old units, so they can be stacked high. Cardboard packing material and the wood bases that accompany new units are also recycled.

Source: Synertech Systems Corp.; photo by Glen Lewis

Why Refrigerator Replacement Benefits Weatherization Programs

Although the original aim of the weatherization program was to save energy used to supply space heating and to help make the housing for lower-income people more comfortable, the high cost of electricity in conjunction with some impressive technological innovations make the replacement of energy-wasteful refrigerators with efficient units very attractive. Here's a list of reasons for integrating refrigerator replacements into weatherization operations:

- Many low-income people have refrigerators that waste energy—at an estimated average annual consumption of 1,200 kilowatt-hours per year (kWh/year) they cost more than $100 per year in most areas.
- Thanks to new federal appliance efficiency standards, the industry has retooled. As a result, very high quality refrigerators are now available that use on the order of 400 kWh/year and cost only $325 to $450 (in bulk purchase), so it is practical to achieve cost-effective savings.
- Electric energy savings offer greater benefits to clients, because, on an energy content basis, electricity costs much more than other forms of residential energy. Clients' electric bills are lowered year-round.
- Electricity savings can mean a great deal to utilities, because refrigerator savings cut peak demand, especially on the hottest days, and modern refrigerators have substantially better power factors than do old units.
- A new, energy-efficient refrigerator is a very visible indicator of weatherization accomplishment to clients and others—and lower electric

Now that refrigerator replacement is an allowable weatherization measure, partnering with weatherization programs is more attractive to utilities, because it costs them less to get the job done.

bills are also most welcome. (Attic insulation also saves energy, but it's out of sight in the attic. A refrigerator keeps the juice cool and is used many times a day.)

- Refrigerator energy education can be a gateway to other important energy use topics in the household.
- Mastering the delivery of refrigerator replacement services constitutes a further professionalization of the weatherization workforce.
- Old, inefficient units are removed from the grid, and the ozone-damaging components and other parts are recycled in an environmentally appropriate way. This helps to reverse the trend of global warming and thereby pleases Mother Nature.

Why Utilities Like Refrigerator Replacement Programs

Many utilities have a growing interest in sponsoring refrigerator replacement programs. This interest can work to the advantage of enterprising weatherization programs, especially as DOE weatherization funds can now be used for replacing wasteful refrigerators. Utilities that get involved in refrigerator replacement programs do so because it builds good public relations and is plain good business. Accordingly, the time is ripe for persuading utility decision-makers to cosponsor weatherization program replacement work.

Securing long-term agreements with major customers certainly contributes to good business for utilities, as illustrated in the NYCHA example. But at any scale, from the generator's point of view, replacing old refrigerators with energy-efficient units helps to shave peak loads and increase power quality. In addition, payment-troubled customers are better able to pay the lower bills after an energy hog is removed from the kitchen. Furthermore, now that refrigerator replacement is an allowable weatherization measure, partnering with weatherization programs is more attractive to utilities, because it costs them less to get the job done. The result can be achieving more ambitious refrigerator replacement projects at lower costs to each party.

Positive Effects on the Grid

The electric grid in the U.S. is an interconnected web of high-voltage lines linking generating plants to users (**Figure 5**). Replacing outdated refrigerators with modern units has two favorable effects on the grid: reduction in peak demand and lowered reactive loads.

Demand reduction. The 74 watts of peak demand saved per refrigerator achieved in the NYPA program will translate into 12.6 megawatts (MW) of total demand savings by the end of the replacement program—enough to supply power to more than 6,300 households. When replacement decisions are made on a selective basis—by replacing only the most inefficient units—both energy and demand savings are even higher. This strategy was used in a pilot demand-side management (DSM) replacement program conducted by Rochester Gas & Electric Corp. It resulted in demand savings of 216 watts (W) per refrigerator replaced (**Table 2**, page 8).[11] A key practical consequence of demand savings is avoiding the need to build new power plants.

Better power factors. Refrigerators built in the 1970s and 1980s have motors that run compressors whose power factors are in the 0.6 to 0.7 range. (See the box on page 8 for some technical background on power factors.) Older refrigerators have compressor motors whose power factors are as low as 0.48. On the other hand, most newer units have more efficient motors plus power factor compensation circuitry so that the loads they present to the grid have power factors of 0.9 or even higher. The net result of new refrigerators is lower reactive loads and less unbillable power supplied to customers.

Figure 5: Map of high-voltage transmission lines in the United States

This map shows all high-voltage (above 230,000 volts) powerlines in the United States as of August 2001.

Source: RDI

Arrearage Reduction and Costs of Terminating Service

As most utilities know from painful experience, the process of terminating service for nonpayment and then restoring service at the same address is a disagreeable and expensive business. A number of utility companies have discovered that targeting payment-troubled customers with conservation programs featuring refrigerator replacements when needed can be a net cost saver. For example, Niagara Mohawk Power Co. has an electricity conservation program for payment-troubled customers that includes up to five measures. These range from refrigerator replacements and waterbed retirement to changing out electric-fired hot water heaters, installing water-saving devices, and replacing incandescent lights with compact fluorescents. As of summer 2001, the program had served more than 3,000 customers.

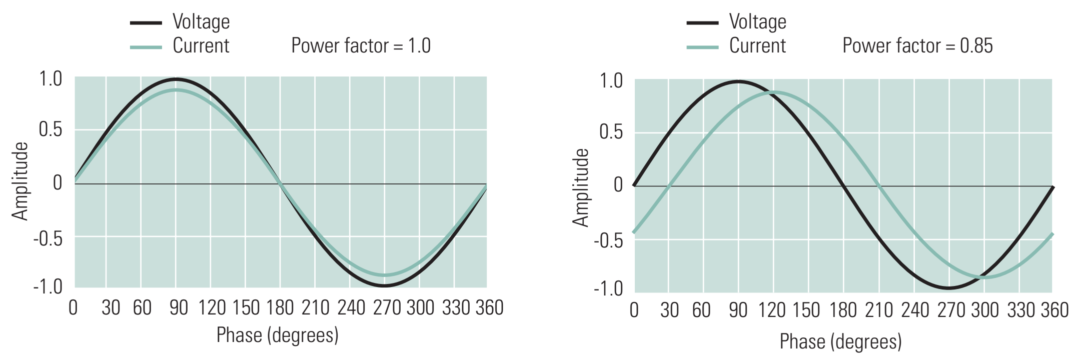
"Our principal aim is to work with people who are behind on their payments to lower their monthly electric bills to the point where they can pay them," explains Kelvin Keraga, regional coordinator.[12] After prescreening potential customers through an examination of their consumption patterns and a telephone interview, the utility performs an energy audit focused on electric usage, using weatherization program people to perform the service in many cases. If the existing refrigerator is not relatively new, the audit includes monitoring the unit with a watt-hour

Reactive Load Reduction

When an alternating current (AC) voltage is supplied to a lightbulb, electric heater, or similar *resistive* load, the current drawn keeps up with the voltage. However, when a voltage is supplied to a motor, transformer, or other device that uses a coil of wire to establish a magnetic field, the current lags behind the voltage a few milliseconds, and the load is said to be *reactive* (**Figure 6**). Most loads seen by a generator at a power plant are to some degree reactive. The power factor associated with a circuit expresses the degree to which it is resistive. A power factor of 1.0 is purely resistive, which allows for the most efficient transfer of power from the generator to loads. Lower power factors—associated with partially reactive loads—are costly to generators, as residential meters only record the resistive portion of the load. Yet generators must supply both the resistive and reactive components, and both cause losses in lines, transformers, and other elements of the power distribution network. Accordingly, utilities tend to promote appliances and other electrical equipment that have power factor–compensating circuitry whose resulting power factors approach 1.0.

Figure 6: Voltage and current waveforms with different power factors

The figure on the left shows the voltage and current rising and falling at exactly the same time, indicating a purely resistive load on the generator and a power factor of 1.0. The figure on the right shows current lagging voltage, indicating a partially reactive load, whose power factor in this case is 0.85.



meter (**Figure 7**) for an hour or more. In about 60 percent of the homes monitored, the existing unit uses enough electricity—1,400 kWh or more per year—to merit being replaced by a new, energy-efficient unit. The program typically installs a 16-ft^3 General Electric Co. (GE) unit, a 19-ft^3 Maytag, or a 21-ft^3 Maytag. If the customer is willing to give up two old refrigerators or a refrigerator and a freezer, the utility supplies a 21-ft^3 model.

Energy education is a large part of Niagara Mohawk's effort, and evaluation results suggest savings of as much as 12 percent result from this educational element alone.[13] Instead of providing a broad barrage of general suggestions, education is focused on two or three very concrete actions customers can take to save energy. A "Partnership Agreement" is signed by the customer and the utility in which Niagara Mohawk agrees to supply

Table 2: Rochester Gas & Electric Corp. pilot refrigerator replacement program results (per-unit basis)

The spectacular savings in this program resulted from replacing only units with very high consumption.

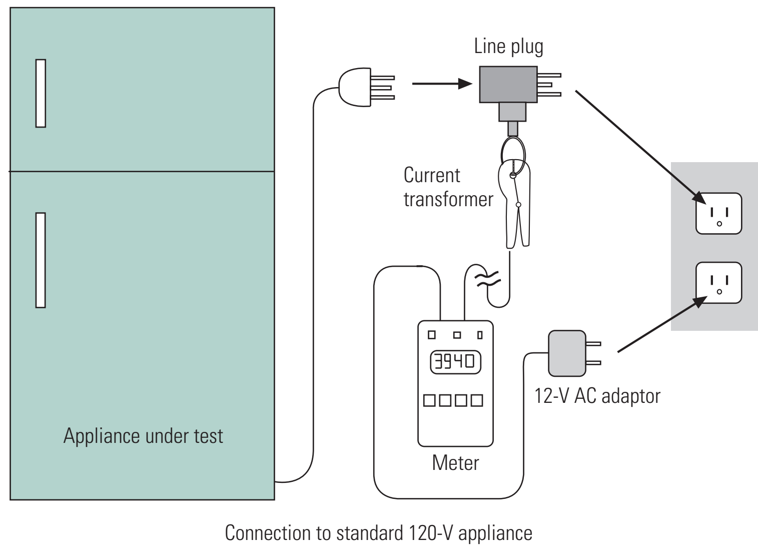
Energy consumption of average replaced unit (kWh/yr)	2,174
Energy consumption of average new unit (kWh/yr)	451
Annual savings (kWh/yr)	1,723
Demand savings (W)	216
Energy savings (%)	79.3
Annual savings ($)	214
Cost ($)	574
Simple payback (years)	2.7

energy education plus appliance efficiency and other conservation services where appropriate. In turn, the customer agrees to undertake specific energy-conserving actions and to pay off debts to the company over an extended period. If the customer keeps the agreement, Niagara Mohawk forgives up to $250 of debt.

Niagara Mohawk's chairman and CEO, William Davis, argues that utility initiatives for low-income customers in the deregulated arena must make "smart business sense." Unlike DSM programs, in which energy efficiency programs were justified only according to avoided costs of providing energy, Niagara Mohawk's low-income program is also justified by "the avoided costs of carrying arrears and decreased write-off of uncollectibles."[14] According to Jack Ziegler, Niagara Mohawk's manager of customer assistance programs, taking into account these criteria, the company's program is very cost-effective. Cut-offs are down, and average annual payments from the customers served by the program are up by $260.[15]

Figure 7: Setup for energy testing used by Niagara Mohawk

This setup for measuring energy consumption of a refrigerator over some time period is used with the Brultech ECM-1200 watt-hour meter (also supplied by Optimum Energy). It measures both instantaneous power draw and energy consumed over the measurement period from 0.001 kWh to 9,999 kWh.



Source: Brultech Research Inc.

How to Run an Effective Refrigerator Replacement Program

"Buy low and sell high" is the not-so-secret mantra of the successful retail merchant. By analogy, "replace the old highs with the best lows" yields cost-effective refrigerator programs.

Choose Energy Efficient, Low-Cost Replacement Units

Securing the "best lows" at a good price has been made a lot easier than it was for the pioneers of refrigerator replacement. In 1995, when NYPA's refrigerator replacement project was still on the drawing board, no major American manufacturer produced apartment-size refrigerators that were either inexpensive or particularly energy efficient. Planners hoped the promise of bulk purchasing would entice a manufacturer to step forward to fill this gap. That's why NYPA developed a request for proposals (RFP) aimed at stimulating refrigerator manufacturers to produce energy-efficient models for this market. The process yielded a 14.4-ft^3 unit manufactured by GE, whose DOE rating is 498 kWh/year—20 percent better than the 1993 DOE standards of 620 kWh/year for refrigerators of its size and class (see box, next page).

Exactly 20,000 of the 14.4-ft^3 GE refrigerators were installed in the first year of the NYPA program, which began in January 1996. The performance of a sample of old and new refrigerators was evaluated, both in the field and in a test chamber designed for the purpose.

In the first program year, field tests were conducted by a third party on 276 refrigerators: 220 on old units and 56 on newly installed units. In addition, a number of tests were performed in the test chamber to study the effects of control settings and ambient temperatures without the influence of other variables (**Figure 8**, next page). Because the DOE test is taken at ambient temperatures of 90° Fahrenheit (F), previous studies of refrigerators showed average label ratios (actual

U.S. Department of Energy Tests and Standards

Setting standards for energy performance assumes that energy consumption can be measured in a uniform, repeatable fashion. The DOE has developed a testing procedure that results in a label rating expressed as kWh per year. For refrigerator-freezer units with an automatic defrost system, the "DOE test," as it is widely known, requires that a unit be run in a test chamber at 90° Fahrenheit (F) until the unit under test reaches steady-state conditions. Then measurement of energy consumed is taken from a given point in the defrost cycle to the corresponding point in the following defrost cycle (typically 12 to 14 hours of compressor run time). The test is conducted with no food load and with no door openings and is repeated changing only temperature control settings.

The results are adjusted mathematically to estimate what the consumption would be with a freezer temperature at 5°F, given that the refrigerator compartment temperature is at 45°F or cooler. Then the energy consumed is normalized to a 365-day year to produce an estimate of annual energy use in kWh. Detailed requirements for the test are given in 10 CFR Part 420, "Energy Conservation Program for Consumer Products Test Procedures for Refrigerators and Refrigerator-Freezers and Freezers."[16]

Table 3[17] shows how the efficiency bar has been raised from 1990, which was the first year standards were put in place in the U.S., through 2001.[18] Data are shown for units with top-mounted freezers and automatic defrost, which are far and away the most popular models of refrigerators on the U.S. market.

Table 3: Maximum allowable annual consumption according to the DOE test

The federal energy efficiency standards for refrigerator-freezer combinations make use of the concept of an "adjusted volume." The adjusted volume equals the actual volume of the fresh-food compartment plus 1.63 times the actual volume of the freezer compartment.

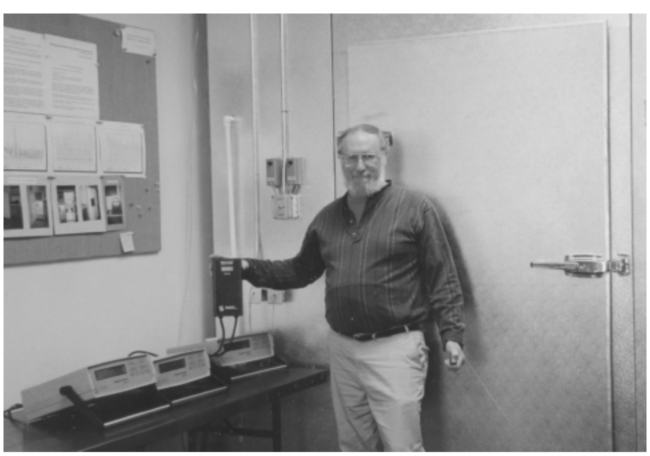
Year of standard	Formula for standard	15 ft^3	18 ft^3	22 ft^3
1990	23.5AV + 471	883 kWh/yr	968 kWh/yr	1,092 kWh/yr
1993	16.0AV + 355	635 kWh/yr	693 kWh/yr	778 kWh/yr
2001	9.8AV + 276	448 kWh/yr	483 kWh/yr	535 kWh/yr

Notes: AV = adjusted volume.
Assumptions: 15-ft^3 unit has a freezer volume = 4 ft^3
18-ft^3 unit has a freezer volume = 5 ft^3
22-ft^3 unit has a freezer volume = 7 ft^3

Source: Isaac Turiel and Sajid Hakim [17]

Figure 8: Test chamber and dataloggers

This chamber can test four refrigerators at a time, monitoring up to 11 streams of data from each. Keeping constant temperatures with refrigerator doors shut allows for studying specific elements of performance while keeping other factors constant. Thus, the effects of control settings or ambient temperatures may be quantified precisely.



Source: Synertech Systems Corp.; photo by Larry Kinney

consumption versus consumption rating by the DOE on the label) of about 0.9 (refrigerators in the field used 10 percent less energy than published DOE test results). By contrast, in this study, the new and existing units had label ratios of about 1.3 (indicating that refrigerators in the field were using 30 percent more energy than in published DOE test results).

New York City apartments tend to be quite warm in both winter and summer, so such results with old units were not too surprising, but the relatively poor performance of the new units was disappointing. It was discovered that the poor performance was primarily because the factory control settings (midpoint, 5 on a scale of 9) kept the refrigerator substantially colder than necessary. As a consequence, NYPA began changing controls to a setting of 2 at installation, and NYCHA began an education campaign to keep them there.

The savings from changing the manufacturer's recommended control setting worked out to be 73 kWh/year, or about 14 percent of the total savings in the first program year.

In subsequent years of the NYPA/NYCHA refrigerator program, a Maytag 15-ft^3 model has been used as a replacement unit under a bulk purchase agreement. It has a DOE rating of 437 kWh/year, which is 31 percent below the 1993 standards. Performance has been very satisfactory at the "midpoint" factory settings, although, as **Figure 9** shows, lowering control settings increases savings substantially. Field measurements show the 15-ft^3 Maytag averages 420 kWh/year in New York apartments (a favorable label ratio of 0.96), even though the average kitchen temperature in NYCHA apartments is 79°F.[19] A new version of the 15-ft^3 Maytag refrigerator introduced in 2001, which bears Magic Chef model number CTN1511GEW (CTL1511GEW for a unit with a hinge on the left) has a DOE rating of 386 kWh/year. Magic Chef model number CTN/L1911GE is a new 19-ft^3 refrigerator whose DOE rating is 440 kWh/year.

Take Advantage of Bulk Purchasing Agreements

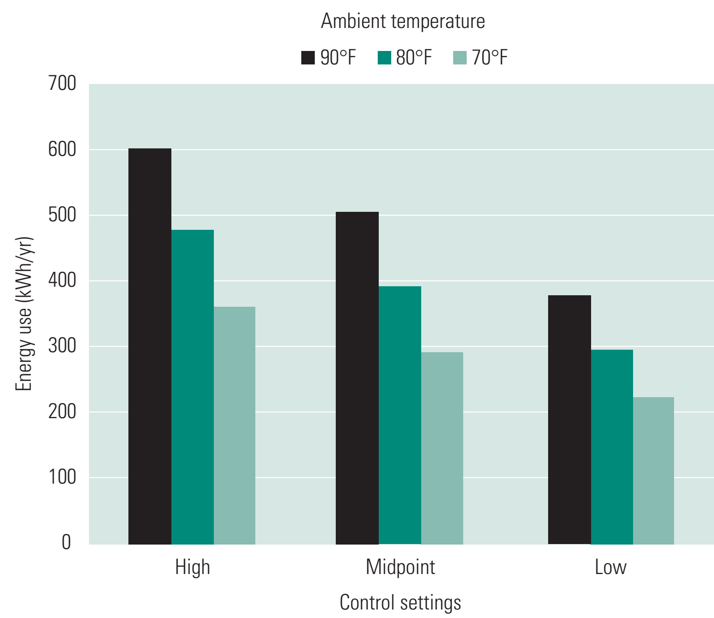
In response to the bulk purchase request for proposals from NYPA, in 1996, Maytag began manufacturing its 15.0-ft^3 Magic Chef Model CTN1511BEW refrigerator, rated at 437 kWh/year. Success with the project led to the development of Magic Chef Model CTN1911DEW, an 18.5-ft^3 refrigerator rated at 485 kWh/year. The larger unit was developed in response to a solicitation from the Los Angeles Department of Water and Power (LADWP), which is involved in several refrigerator replacement projects. The 15-ft^3 model is only 27.5 inches wide, which enables it to fit into narrow spaces and replace 12-ft^3 units frequently found in apartments.

Manufacturing for bulk purchasing achieves good economies of scale for Maytag, because the company can plan production more effectively. Bulk purchasing also circumnavigates many of the costs associated with intermediary agents and traditional sales. The result for organizations conducting replacement programs is an energy-efficient refrigerator at a very attractive price.

In general, other refrigerator replacement operations can piggyback on the bulk refrigerator agreements negotiated by the NYPA (for the 15-ft^3 unit) and the LADWP (for the 18.5-ft^3 units). Organizations interested in these and other details on bulk purchasing should contact Melissa Lucas at the Consortium for Energy Efficiency, an organization funded by the DOE to expedite implementation of a wide range of appliance efficiency programs.[20]

Figure 9: The influence of control settings and ambient temperature on energy performance

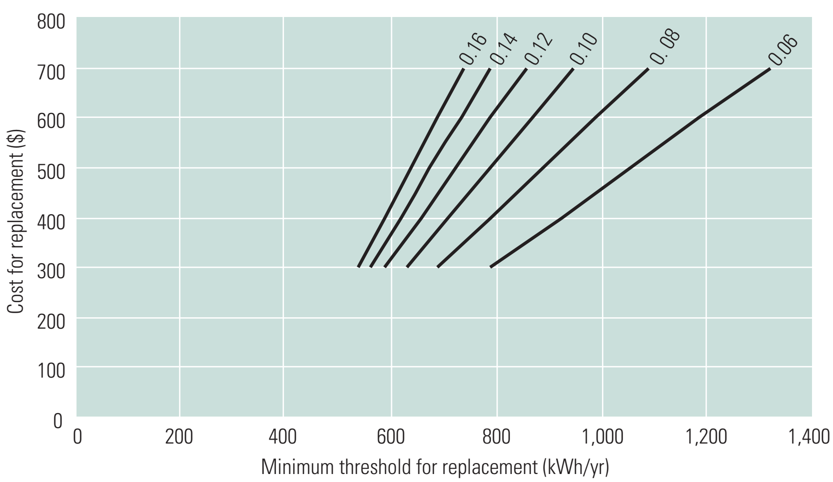
Much has been made of the strong effect of ambient air temperature on refrigerator performance, but control settings play a key role as well. This data was collected from a Maytag 15-ft^3 refrigerator in a chamber with no food load or door openings. Annual consumption at high control settings in a 90°F environment is 2.65 times the annual consumption at low control settings in a 70°F environment! Even in a 70°F ambient environment, consumption at a high control setting is 1.57 times that at a low setting. This illustrates the importance of consumer education, especially at the point of installation of the new refrigerator. Using ovens to heat kitchens and keeping controls high both waste a lot of electricity.



	Average temperatures at each control setting (°F)		
Compartments	High	Midpoint	Low
Fresh food	36.4	38.8	43.9
Freezer	–9.1	1.6	12.4

Figure 10: Energy costs and replacement costs to achieve a unity SIR

Points on the electricity cost curves corresponding with given replacement costs on the vertical axis are associated with points on the horizontal axis representing the minimum annual energy that an old refrigerator must consume to achieve an SIR of 1. The curves are set up so that a planner may start out knowing local electric energy cost and the total cost (including administrative) for replacing and recycling old units and may derive a value of annual kWh consumption for an SIR of 1. Alternatively, one may start out with a minimum annual energy use of a refrigerator and determine the maximum cost of replacement that will yield an SIR of 1. Assumptions: Replacement unit has an annual consumption of 386 kWh/yr and a lifetime of 20 years. The discount is 4.8 percent.



Pick Your Shots

The more an old refrigerator consumes, the more cost-effective it is to replace it with a new one. Accordingly, two key questions need to be addressed in planning and conducting a refrigerator replacement program. First, what is the least amount of energy an old unit should consume to merit being exchanged? Second, what is the most practical way to determine if a given unit consumes energy at rates above the threshold for replacement?

Determine the threshold. A useful way to plan a refrigerator program is to express the threshold for changing a refrigerator in terms of savings-to-investment ratios. SIR is the ratio of the savings expected from a conservation measure over its lifetime (discounted to the present time) to the investment necessary to implement the measure. Hence, an SIR of greater than 1 is deemed cost-effective. For example, an agency might elect to change out only those old refrigerators that have SIRs of 1 or more. Such a decision will guarantee a cost-effective program, because, if all the refrigerator replacements have SIRs of 1 or above, the average will be substantially greater than 1. **Figure 10** shows a family of curves for defining the threshold where SIRs become 1.0 when the replacement unit will have an annual consumption of 386 kWh/year (like the new 15-ft^3 Maytag unit).

Figure out how much old units consume. Unhappily, old refrigerators don't have annual consumption figures written on them. Nonetheless, knowing how much they consume is clearly critical to managing a refrigerator replacement program and quantifying savings.

One approach is to change all refrigerators of a given class—for example, all refrigerators in a group of housing authority apartments not owned by tenants. Evaluation of the New York replacement project after its second year of operation shows that this approach is cost-effective, although the payback time approaches 10 years. Costs for changing out are low, because no time is wasted in deciding if a given unit should be changed. All tenants are given nice new refrigerators, so nobody can complain.

A modification to the "replace 'em all" approach is taken by the Stark Metropolitan Housing Authority in Canton, Ohio, which simply replaces all units manufactured before a particular date, in this case, 1994. Michael Williams, the energy manager for the housing authority, says his program uses only 15-ft^3 bulk-purchased Maytags for replacements, which the housing authority gets for $335 delivered. He estimates energy savings at $54 per year, for a respectable simple payback of six years.[21]

Operators of Wisconsin's refrigerator replacement program are using a similar method, only they are replacing units manufactured prior to 1990, the first year DOE standards were implemented. In reaching this decision, the state conducted a survey of household appliances in 355 households whose members are eligible for weatherization assistance. The survey found that all households surveyed had refrigerators, but only 10.4 percent had second refrigerators. On the other hand, 49 percent had one or more freezers. Of significance in adopting Wisconsin's replacement policy, the survey indicated that approximately half of the refrigerators were manufactured in 1989 or before.

"We think this method makes good sense in Wisconsin," reports Jim Cain, the program's planner. "In addition to allowing agencies to change out all the old units, we also allow replacement of refrigerators that are broken (or run all the time), have a measured usage of over 1,300 kWh per year (based on at least a two-hour field test), or have a demand of over 250 watts (except when the defrost heater is on). We think the net result will be a cost-effective replacement program that isn't unduly burdensome for the local agencies to run."[22]

At the other end of the spectrum, in a pilot project for RG&E, all refrigerators were monitored for a period of between an hour and more than a week. This "taking the cream" approach achieved spectacular savings among the units replaced, but monitoring costs were substantial. (However, in this case, these costs were paid for by a third party that was principally interested in evaluating the range of older refrigerator performance in the field.)[23] The Niagara Mohawk program briefly monitors all refrigerators it plans to remove, but the "hit rate" is high, because the pre-audit interview and bill examination process already suggests likely candidates for replacement.

Finally, in a pilot replacement project in Iowa begun in 1999, all refrigerators and freezers were monitored for hours, days, and weeks during summer and winter conditions. The information received was used to determine a short-term metering process of two hours. This process is integrated into the comprehensive home audit conducted for weatherization, so the incremental cost to conduct it is small. "This works fine for us," reports Mark Bergmeier, weatherization program trainer, "and we can collect evaluation data that helps us track savings."[24] This information is of interest both to the weatherization operators in the state and to the utility company that has supported refrigerator replacement. Iowa's electric rates for residential customers are $0.083 (about the national average), but the program is averaging a $108 annual savings per replaced refrigerator for an overall SIR of 1.8.

A middle way. There appears to be a broad middle-ground approach that lies between monitoring no appliances and monitoring all of them. It begins with some empirical observations about several classes of refrigerators. Not all old refrigerators waste substantial energy, but most do. Those that are less wasteful tend to be relatively new—manufactured under 1993 standards, for example—or do not include automatic defrost. Many in the latter group are quite old, and some 12-ft^3 models have run at a consumption rate of 500 kWh/year or even lower for half a century (although their power factors are typically around 0.50).[25]

There appears to be a broad middle-ground approach that lies between monitoring no appliances and monitoring all of them.

On the other hand, many old units become wasteful over time due to frequent movement or wear and tear. Cracks in the inner lining and tears in old fiberglass insulation soon result in air leakage, condensation, ice formation in the insulation, and rapidly declining performance. Finally, 1 in approximately 50 old refrigerators develops a slow leak in refrigerant. The result may be manifested by soft ice cream, warm soda, and virtually continuous compressor runs—all undesirable consequences. Some—not all—relatively new units manufactured between 1985 and 1990 have quite poor energy performance. Old hands report (and both DOE and field tests verify) that side-by-side models colored bronze, gold, or avocado routinely use 1,800 kWh/year or even more.

Given these observations, Dennis Flack, who runs a number of refrigerator replacement programs for CSG, has honed CSG's approach to choosing the right units to replace. "Five or six years ago, we relied more on measurement than we do now," Flack reports. "For most customers, we use a combination of observation, wisdom from the past, and some easy-to-use software we developed using data from AHAM [Association of Home Appliance Manufacturers] and field measurements."[26]

The observation part requires some training but is not very complicated. If a refrigerator is functional, new, or only a few years old (and thereby meets 1993 standards), they don't replace it unless it's not working well. If it's an old manual defrost model on its last legs (or a side-by-side unit with an odd-ball color), they replace it. In all other cases, they try hard to find a name plate and model number to see if they can get a fit with their database. Much of the database is derived from information contained in the *Appliance Information Reference* published by AHAM.[27]

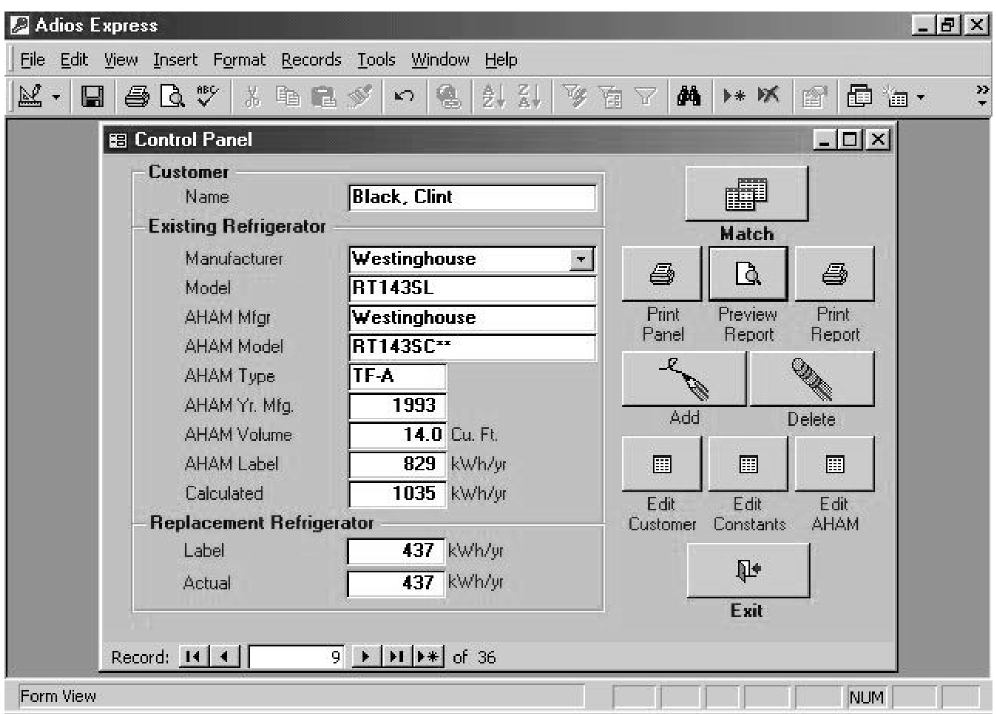
The *Reference* contains information on brand name, model number, year of manufacture, size, and results of DOE testing in estimated kWh/year for many residential refrigerators. The 1995 *Reference* contains information on more than 45,000 models sold under 131 brand names in the United States. Nonetheless, there are a number of years for which DOE testing information is missing, and there are some models found in homes that are not listed in the AHAM *Reference*.

The DOE ratings are based on measurements on new refrigerators, of course. Sometimes field measurements of old units indicate that they've maintained their energy performance pretty well, but, on average, field measurements show that older refrigerators fall off in performance by 20 to 30 percent over the years. The software CSG uses allows for applying a correction factor to the DOE number (**Figure 11**).

Another available measurement tool is the national energy audit tool (NEAT), a Windows™-based software package developed by the Oak Ridge National Laboratory (ORNL) for the DOE's weatherization program. Version 7, an upgrade of the NEAT software released in the summer of 2001, includes procedures for refrigerator auditing. The software has information on many thousands of residential refrigerators from the AHAM database. This includes manufacturer, model number, year of manufacture, size, and—

Figure 11: Control panel for Adios Express software

In practice, a label on a refrigerator in the field can be exactly (or very closely) matched with one in the database. The annual energy use from DOE testing is multiplied by a factor that varies with age (here 1.25) to produce an estimate of the annual consumption of the unit in the field, in this case 1,035 kWh per year. Note that the replacement unit's performance is estimated at 437 kWh per year. Because the estimated savings will thus be 598 kWh per year, a decision to replace will probably be made. If it is, a click of the mouse enters the information into a "units replaced" master database for subsequent reporting.



Source: Dennis Flack, CSG [29]

most important—the results of the DOE energy consumption test. Like Adios Express software, NEAT includes factors that increase estimates of annual consumption as a function of the age of the units. According to Michael Gettings, the software's developer at ORNL, NEAT adds 10 percent to the DOE test for units between 5 and 10 years old, 20 percent to the DOE test for units between 10 and 15 years old, and 30 percent to units more than 15 years old.[28] Because NEAT is free to weatherization program operators and may be used even if other elements of the software are not, it can be a useful tool in making decisions on refrigerator replacement. Weatherization program operators may obtain the software for free through their state's weatherization program director.

When and how to test. The preceding procedures represent a practical compromise between a "test 'em all" and a "change 'em all" strategy. Of course, circumstances arise in which there's no clear way to make a judgment on replacement without testing actual consumption. Some middle-aged units are found to be without manufacturers' labels; Dennis Flack estimates this is true for, at most, 2 percent of units. On another 20 percent, there is no DOE test data from the AHAM database, but roughly half of these have model numbers that are quite close to those for which there is DOE test data.[29] If a number of units are found in an apartment complex, for example, for which no DOE test data is available, testing is clearly appropriate. Furthermore, most program operators find it useful to test a sample of units to verify their decision-making strategy and to evaluate savings. In all such cases, field testing of actual performance using at least a watt-hour meter is desirable.

A number of companies produce watt-hour meters (see Appendix, page 27).

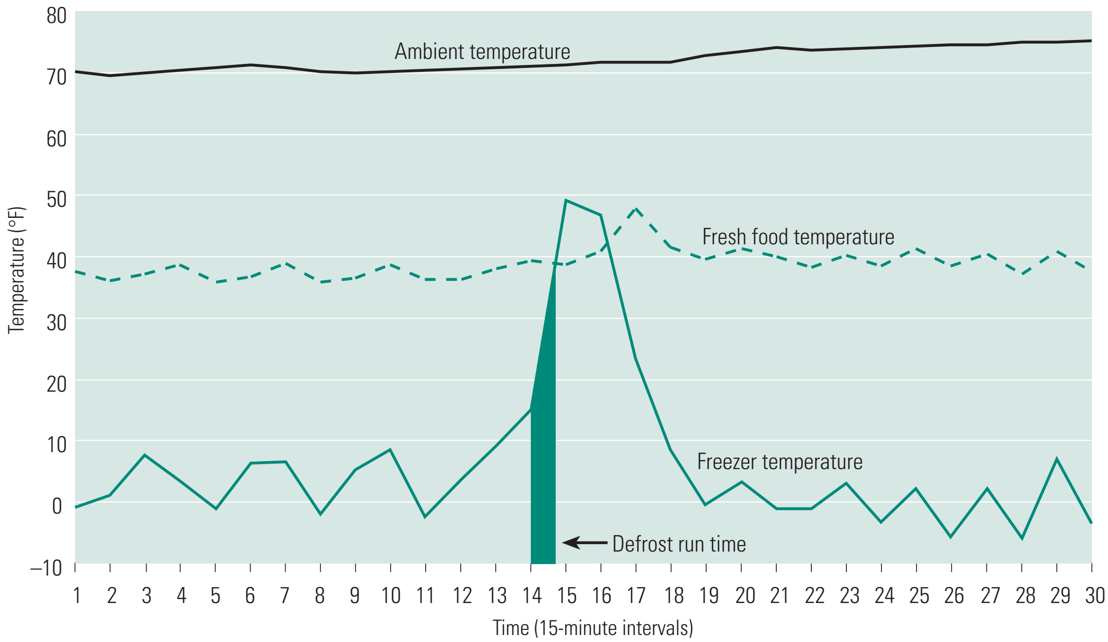
It's tricky to get an accurate estimate of a refrigerator's energy use over 8,766 hours (one year) by testing for only an hour or so. Defrost cycles during a short test can completely distort results, and kitchen temperatures during the test that are substantially different from annual ambient temperatures can also produce errors. On the basis of a number of field and chamber tests conducted by Synertech Systems Corp. with 11-channel dataloggers,[30] we make the following recommendations:

- How measured data is to be used is an important consideration in planning a field test. Gathering data to make a simple, binary "replace/don't replace" decision generally requires less accuracy than gathering sample data for evaluating program savings.
- One-hour tests usually generate insufficient data to draw useful inferences, as they are within 10 percent of an accurate estimate only 18 times out of 100. Three-hour tests are within 10 percent of an accurate estimate 90 times out of 100.
- Given the percentages above, the longer a refrigerator test, the better. The "natural period" of a frost-free refrigerator is from the beginning of a defrost period to the beginning of the next defrost period, which can range from 16 to 40 hours, depending on use, control settings, and ambient temperature and humidity (**Figure 12**, next page). (Some new models have many "mini" defrost cycles, which make it easier to estimate annual performance with shorter-term data.)
- Food loading affects test results. When very short-term tests are conducted (under four hours), doors should be kept shut. If the occupant has recently loaded the refrigerator with warm food or drinks, the compressor will run substantially more than usual for several hours. In this case, testing should be delayed or extended.
- If a defrost cycle occurs during short-term testing, the test should be extended (preferably to 24 hours) or abandoned. If it does not occur, a correction factor of 8 percent should be added when normalizing data to account for the effects of the energy used to defrost plus the extra compressor energy necessary to remove the heat. Simply multiply the measured estimate of annual refrigerator energy use by

Gathering data to make a simple, binary "replace/don't replace" decision generally requires less accuracy than gathering sample data for evaluating program savings.

Figure 12: Effect of defrost cycle on fresh food and freezer compartment temperature

This new 14.4-ft^3 GE refrigerator shows substantial swings in temperature over a defrost cycle. A 400- to 450-watt heater is used by most manufacturers. In this case, 355 Btu of heat was dumped into a freezer compartment during a 13.45-minute defrost period. In the absence of the thermal mass that would be associated with fully loaded compartments (this field data is taken on a partially loaded refrigerator), temperatures in the frozen foods compartment dwell above 32°F for more than 20 minutes. This phenomenon is a leading cause of crystals in ice cream.



Source: Synertech Systems Corp.

1.08. As of writing this report, E SOURCE knows of no supplier of small watt-hour meters suitable for field testing that signal the occurrence of a defrost run during the testing period, but at least one (Watt Stopper) has plans to develop such a feature.

- If there is good reason to suspect that the ambient temperature during the test is substantially different from the average temperature over the year, a correction factor of 2.5 percent per degree F difference should be applied to the result. (If the temperature during the test is cooler than the annual average, the correction factor should increase the estimated annual consumption and vice versa.) For example, if a test is taken on a cool day when the kitchen temperature is 67°F, but the home has no air conditioner and is in a climate zone where summers are long and hot, you and the resident may conclude that the average kitchen temperature over the year is 72°F. Thus, the estimate of measured performance should be corrected by 72 – 67 = 5°. At 2.5 percent per degree, the correction is 5 x 2.5 percent per degree = 12.5 percent. Thus, the measured estimate of annual refrigerator usage should be multiplied by 1.125. In the case of a test taken during the summer when the kitchen temperature is 80°, yet 71° is a good estimate of the client's annual kitchen temperature, the correction should be applied as follows: 80 – 71 = 9 degrees difference; 9 x 2.5 percent per degree = 22.5 percent. In this case, the measured estimate of annual refrigerator usage should be multiplied by 1 – 0.225 = 0.775.

Team Up with Utility Programs

Teaming with utility programs can save weatherization programs costs and multiply the number of people that agencies can serve. However, in deciding on lower thresholds of annual

Improving Accuracy: Comparing Apples with Apples

The "DOE test" for refrigerator efficiency attempts to estimate annual performance based on measuring the consumption of a refrigerator over its natural cycle and then normalizing the data for a year. The controls are adjusted to maintain an average freezer temperature of 5°F and a fresh food compartment temperature of 40°F. Although the refrigerator is tested empty with no door openings, the test is conducted in a chamber at 90°F. The test is subject to inaccuracies, but at least all refrigerators are tested according to the same procedure. By analogy with EPA's testing of automobile fuel efficiency, "your actual mileage may vary."

In the actual world, refrigerator performance varies as well. Refrigerators are exposed to different control settings, daily and seasonal changes in ambient temperature, plus a wide variety of patterns of food (and drink) loading and door opening durations. It is thus not at all surprising that field measurements of refrigerator energy performance vary substantially from DOE test results; they are sometimes higher, sometimes lower.

In the light of these observations, should DOE test results be ignored in favor of short-term tests?

Let us first consider the accuracy of short-term testing. The aim is to estimate performance over an entire year based on the measurement of a few hours of refrigerator performance. The only way to accurately assess the error associated with a test shorter than one year is to measure for one year, then compare the results with what would have been estimated from various shorter-term tests. Even if a short-term test is conducted over the natural refrigerator cycle—from the beginning of a defrost period to the beginning of the next—the particular period measured may not be representative of average loading patterns or (probably more important) ambient temperatures. Refrigerator energy consumption varies roughly 2.5 percent per degree F change in the temperature of the environment, and kitchen temperatures change substantially from season to season. Of course, you risk larger errors if you take smaller samples, because the effect of defrost periods will be overestimated or underestimated depending on whether the period included a defrost run.

So what is the best policy for making rational decisions about replacement and estimating savings achieved? What is really at stake is neither the consumption of the old refrigerator nor the consumption of the new one but the *savings* achieved by retiring the old unit and placing the new unit in service. The difference in the DOE ratings of the old and new unit is likely to be more accurate than the DOE ratings of each unit. It's the same case with short-term field testing of the old and new units. Whatever errors occur in the testing of the old unit are likely to be similar to the errors in testing the new one, so in calculating savings the errors tend to cancel each other out.

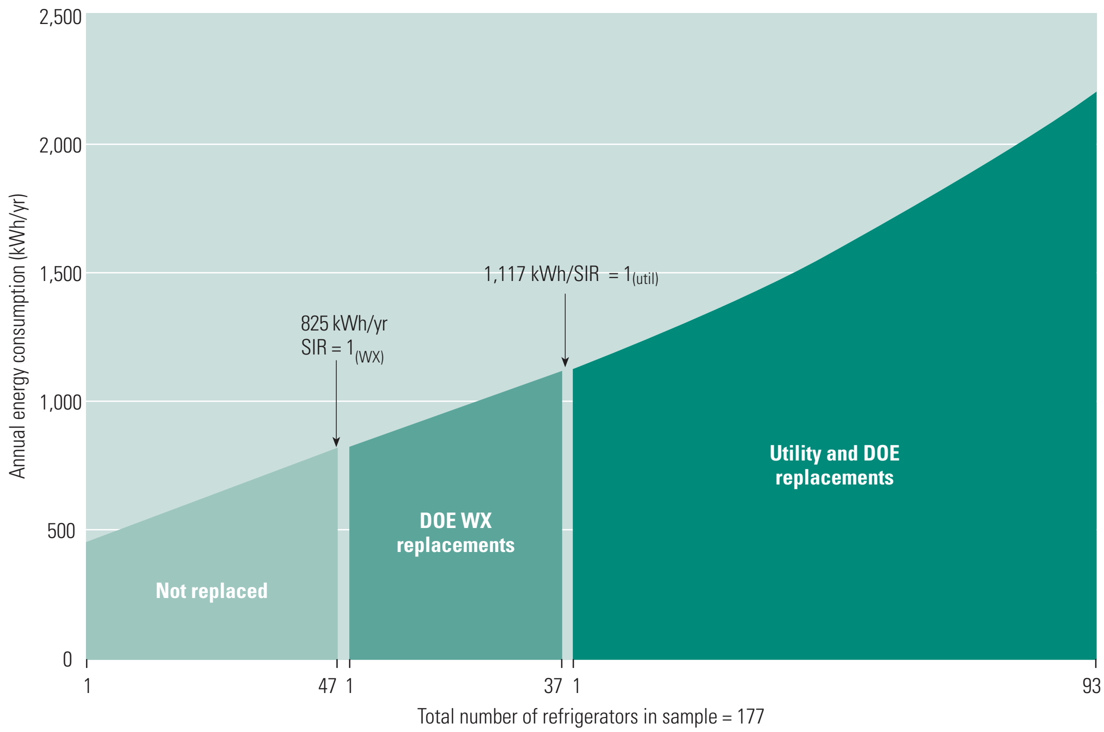
In practice, this suggests testing a sample of new refrigerators in the field, *using the same techniques used to sample old ones*. When replace/no replace decisions are made by testing old units, the potential savings should be compared with results from these measurements. When replace/no replace decisions are made on the basis of DOE ratings on the old units, they should be referenced to DOE ratings on the new units.

consumption that old refrigerators must meet in order to meet cost-effectiveness criteria, sometimes utility planners compute savings based on their avoided costs for electricity rather than the substantially higher costs actually paid by customers per kWh of electric energy use. Of course, this effectively raises the threshold for eligibility to the point where the number of units that can be cost-effectively replaced using utility criteria may become a small percentage of the whole. This means that fewer people can be served, and the cost of providing services is increased, because many more units must be inspected for each unit replaced.

A solution to this problem that may be practical in some cases is to combine DOE weatherization funds with utility funds so that utility funds are used to replace the most wasteful units and DOE funds are used to replace other units that are cost-effective from the point of view of retail electric rates (**Figure 13**, next page). This can result in an overall efficient program in which field procedures are simplified, yet effective use is made of all

Figure 13: Replacement disposition of a sample of old refrigerators

This example of a group of existing refrigerators is ordered according to the units' estimated annual energy use. Refrigerators in the low-energy-use category are sufficiently energy efficient that they should not be replaced, because SIRs would be less than 1 from any perspective. Units in the middle category are cost-effectively replaceable from the perspective of the retail electric rate payer. The highest-energy-using units are cost-effectively replaceable from all perspectives, including that of the utility.



resources. Of course, it is important to adopt office procedures to account for units replaced by funding source.

Provide Customer Education

As the saying goes, "Houses don't use energy, people do."[31] Indeed, electric energy consumption in particular is often a function of occupant choices and behaviors. While a new, energy-efficient refrigerator offers profound benefits in and of itself, occupants can sabotage savings or maximize performance, depending on their understanding of (and commitment to) smart operating procedures. Therefore, influencing and supporting families to learn and choose energy-conserving behaviors is a vital aspect of weatherization refrigerator replacement work.

At the beginning of the Chicago Housing Authority's refrigerator program, only modest attention was given to customer education. Now the staff spends more time educating its residents in the operation and proper use of the new units. According to the program's director, Dave Anderson, "we've found that additional education at the time of installation can reduce complaints from the residents and increase savings by instructing the residents on where to set the temperature controls."[32]

"When it comes to electric energy client education, it is not something we do *to* people, but something we do *with* them," notes Alan Chapman, Minnesota's energy programs field supervisor, who facilitates weatherization participation in mandated electric utility low-income conservation programs. "We don't tell them what they should do; we find out what they're *willing* to try, and we put a lot of time into understanding how they use their appliances, how they feel about their electric bills, and what they want to get out of being a partner with us to reduce those bills."[33]

Facilitate learning. Effective energy-efficiency educators manage the flow of content, experience, and feedback in response to the occupants' specific circumstances.[34] Being clear about the content allows for greater creativity in style, timing, and delivery of the education. Adult educator Lydia Gill-Polley puts it this way: "Taking a learner-focused approach is a shift from telling people what to do to working together to be sure they have the knowledge, understanding, skills, and commitment to carry out chosen actions."[35]

Malcolm Knowles, a leading authority on adult education, says that, as a teacher, he had "been trained to perceive my role as essentially that of content-transmitter and judge of the students' absorption of the transmitted content."[36] He describes his transformation from "teacher" to "facilitator of learning" as follows: "This may seem to be a simple and perhaps even superficial change. But I found it to be fundamental and terribly difficult. It required that I focus on what was happening in the students rather than on what I was doing. It required that I divest myself of the protective shield of an authority figure and expose myself as *me*—an authentic human being, with feelings, hopes, aspirations, insecurities, worries, strengths, weaknesses. . . . It required that I extricate myself from the compulsion to pose as an expert who had mastered any given body of content and, instead, join my students honestly as a continuing co-learner."[37] As a facilitator of learning, he performs primarily as a procedural guide and designs a "process structure rather than a content structure. The difference is not that one deals with content and the other does not, but that one is concerned with the transmission of content and the other with the acquisition of content."[38]

So, an effective adult educator is one who facilitates the acquisition of content (facts, skills, processes, new ideas, attitudes or values) by the clients (learners).

Establish clear learner objectives. People can absorb only limited content and make few active behavioral changes at a given time. This is one of the reasons that, in spite of decades of colorful brochures offering "101 Easy Energy Saving Tips" and the like, few people are aggressive energy conservationists. Tests have shown that people remember 20 percent of what they hear, 40 percent of what they hear and see, and 80 percent of what they discover for themselves. If the educator is thoroughly acquainted with the range of applicable issues and actions associated with energy-efficient refrigerators, she may select the two or three most important learner objectives as priorities for a particular family.

Relate energy use to the monthly bill. While the national spotlight is on electricity cost, supply, and reliability, customers' attention is likely to be more easily directed to the impact of refrigerator energy use at the household, grid, and environmental levels. Because refrigerator energy use can account for 9 to 25 percent of a household's annual electric bill, it is a significant contributor to the bottom line, and both hardware and behavior make a difference.

Understanding the relationships between appliances, use habits, and utility bills is an important aspect of taking control of electricity use and costs. Because energy is largely "invisible" to most people, they may lack the ability to connect the consequences of alternative circumstances (like efficient refrigerators) and behaviors (like setting thermostats for savings). Refrigerator assessment and replacement is somewhat unusual in home weatherization programs, because the chain of circumstances and energy use is clearly reflected on the utility bill. The projected annual energy (kWh) savings due to the new refrigerator can be expressed as an average monthly fraction in both energy and dollars. There is a high likelihood that program participants will be able to see the expected reduction in their monthly electric bill. In addition, learning to use this common feedback device is useful beyond the bounds of refrigerator replacement. When end users make the connection between energy savings throughout

Effective energy-efficiency educators manage the flow of content, experience, and feedback in response to the occupants' specific circumstances.

Understanding the relationships between appliances, use habits, and utility bills is an important aspect of taking control of electricity use and costs.

Educate Contractors and the Public

Contract delivery crews also need to clearly understand a refrigerator replacement program's expectations and their role. Regrettably, some have displayed a social bias that undermines the primary efforts to support occupants in taking control of their home environment and energy use. This may manifest itself in snooty comments about the home environment or poor people not deserving such a benefit, and so on.

This type of situation underscores the importance of educating not only those whose appliances are being replaced but also those doing the replacement work. One approach to this task might involve connecting with trade allies (or legislators and program board members) to help articulate the larger benefits of refrigerator replacement programs to the community and society.

their household and lowered energy costs, the results can be dramatic.

Share Ideas on Saving Opportunities

The first most obvious savings opportunity lies in getting rid of multiple units. It is not unusual to find two (or more!) refrigerators in a household. The anecdotal record goes to Pam Downey, owner of PD Associates Energy Services in Ralston, Pennsylvania, who recalls, "I was doing a low-income baseload inspection for an electric utility, and going into it I knew the usage was high. But I was unprepared to find five running refrigerators in one house; it took all my skills to engineer the removal of the extra units and up-size the main replacement refrigerator."[39]

Here are some additional savings ideas:

- *Check thermostat settings.* Thermostat settings lead the list of important elements to include in effective client education. Leaving thermostat controls at their coldest setting means that the refrigerator has to work harder to maintain the large difference in temperature between its inside and outside. It also means that the refrigerator needs defrosting more often (whether or not defrosting is automatic).
- *Choose location carefully.* Locating a refrigerator or freezer next to a heat vent, radiator, or sunny window increases energy use.
- *Avoid increasing ambient temperature.* Using the kitchen range as a space heater is not only dangerous, it also exacts an energy penalty on the refrigerator.
- *Keep antisweat heater off whenever possible.* Leaving the antisweat heater on when ambient humidity levels are low is simply wasteful.
- *Precool refrigerated items.* Precooling food or beverages before loading them into either compartment almost always makes sense. Because air is cooled in the freezer and directed to the fresh food compartment with fans and louvers, placing large masses of warm foods or beverages into the freezer compartment not only makes the compressor run especially long, but it may also result in freezing the lettuce.
- *Cover food and drink.* Uncovered items raise the humidity in refrigerators, causing increased compressor run time and energy waste. Uncovered food left in a refrigerator for very long tends to taste bad, too.
- *Clean.* Cleaning is a basic maintenance requirement that applies to nearly everything. Refrigerators are no exception. Dirty door gaskets can stick, tear, and lose their seal; dust and crud buildup on condenser coils may not be a significant energy issue, but routine cleaning is nonetheless wise.

Prepare and Use a Brochure or Fact Sheet

Tips for optimal refrigerator operations abound; a selection is available at www.eren.doe.gov/buildings/consumer_information/refrig/reflink.html. It is important that weatherization staff focus people's attention on those actions that offer the greatest return for their efforts rather than overloading residents with too many tips.

The following items might usefully be included in a client brochure. Some from the second list might even be included on a refrigerator magnet (along with the local agency's logo and phone number).

For the smoothest installation

- You will be notified when your new refrigerator will be installed. Please be available at that time, and call at least 24 hours in advance if you cannot keep that appointment.
- Cooperate with the delivery and installation team. Refrigerator doors can be hinged on either side; be sure yours is correct.
- It will be easier to transfer food if you don't shop right before you receive your new refrigerator.
- Be prepared to clean behind the old refrigerator before the new one is installed.

To get the most from your refrigerator

- Unplug or get rid of second refrigerators.
- Set thermostat controls to avoid overcooling food and beverages—36°F to 38°F for the fresh food compartment and no less than 5°F in the freezer.
- Understand and use the energy/power saver switch feature. It keeps moisture from condensing on outside surfaces.
- Cover food containers tightly to reduce evaporation and keep food moist and fresh.

Conditions That Promote Adult Learning

Studies show that adults learn most readily when

- They recognize a personal benefit from acquiring knowledge or a skill.
- They see an *immediate application* for the information or skill.
- They are involved in solving *specific problems they have identified*.
- They are encouraged to "*test the information*" against their own experience.
- They see that *respect and trust* are active elements of the teaching-learning situation. [40]

As suggested in **Table 4**, there are potentially many "teachable moments" during the weatherization process that meet these criteria.

Table 4: Teachable moments for refrigerator client education

Virtually everyone who contacts the customer can be called upon to play a useful role in customer education.

Intake	Scheduling	Audit/assessment	Work/installation	Final inspection
Introduce program purpose and state expectation that participatants are partners in achieving maximum benefits: "The purpose of our program is to work together to discover ways we can save energy, so you'll have a bit more money and be more comfortable and healthy in your home."	Express time requirements for interview, house tour, diagnostics, and so on. Ask how many refrigerators and freezers there are, and ask that the top of the primary unit be cleared to facilitate inspection and energy use assessment.	Detailed discussion of number of units, use, problems, food loading and storage patterns, ambient temperature, demonstration and practice with (thermometers and) control settings. Data collecting and, perhaps, metering. Establish maintenance needs and witness action commitments.	Be present for "teachable moments," reinforce control settings, leave brochure and warranty/help information.	Explore realized benefits. Review electric bill. Reinforce successes. Problem solve as needed. Confirm understanding of benefits.

- Avoid overheating the room—especially don't use the stove as a space heater. This can lead to carbon monoxide poisoning or fire. It isn't healthy for you or your refrigerator!
- Let hot food cool some before loading it into the refrigerator. Cooling it in a chilly water bath is far quicker than letting it sit at room temperature; it's safer, too.
- Be sure the door closes tightly after every opening.
- Clean door gaskets and condenser coils regularly, and allow air to circulate freely around the appliance.

If you have questions

- Keep the warranty papers where you can find them.
- Call the refrigerator vendor at [insert number].
- Contact the community action agency or contractor at [insert number].

"Environmental values are already intertwined with core American values."
—Willett Kempton

Articulate Environmental Benefits

Although efficient refrigerators offer the benefits of reduced energy use and bills, they also offer social and environmental effects that run deep. Willett Kempton notes that "environmental values are already intertwined with core American values."[41] Although many people are not clear about the connections between electricity use and environmental degradation, recognizing and building on this self-interest offers a great opportunity.

According to the 1989 Oak Ridge National Laboratory report *Weatherization Works: An Interim Report of the National Weatherization Evaluation*,[42] the lifetime weatherization program energy savings (up to 1989) equaled a forest planting the size of the Smoky Mountain National Park. Annual savings were the equivalent of the emissions of a 40-MW coal plant, and every four weatherized houses saved the equivalent of the emissions from one car. Including refrigerator replacement in the weatherization program seems sure to improve these desirable environmental consequences, because efficient refrigerators decrease the amount of electric generation needed. Reduced generation decreases the associated pollution of acid rain, global warming (climate change), mining, fuel transportation and storage, and waste disposal.

Recycle Old Units

All refrigerator units replaced must be properly disposed according to the environmental standards in Clean Air Act.

In the first round of its refrigerator replacement program, the Chicago Housing Authority contracted with an inexperienced resident-owned firm to recycle the refrigerators that it switched out. Instead of being recycled, many of the older units were resold and remain as wasteful energy guzzlers in the kitchens of low-income families. Now, CSG, the contractor that conducts the replacement work in Chicago, is extending its services to include recycling services.

Ensuring that removed refrigerators are taken out of service and "demanufactured" in an environmentally appropriate fashion is obviously sound environmental and energy policy. This is reflected in Weatherization Program Notice 00-5 and Appendix A of the current version of program regulations, to wit: "All refrigerator units replaced must be properly disposed according to the environmental standards in Clean Air Act (1990) section 608 as amended by Final Rule, 40 CFR 82, May 14, 1993."[43]

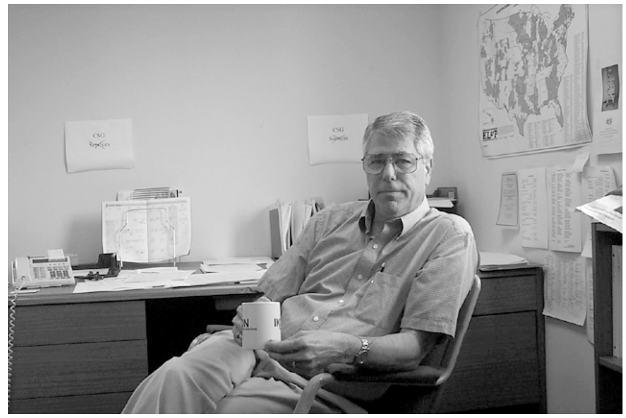
Under most circumstances, recycling refrigerators is generally not very expensive ($20 to $30 per unit), because the providers of demanufacturing services can make some profit on recycled materials. In all events, by DOE rule, the cost of recycling must be included in overall costs of refrigerator replacement for purposes of computing cost-effectiveness.

The photos in **Figure 14** show how a refrigerator recycling operation in Syracuse, New York, accomplishes environmentally appropriate demanufacturing of old units.

Figure 14: Demanufacturing old refrigerators: A photo essay

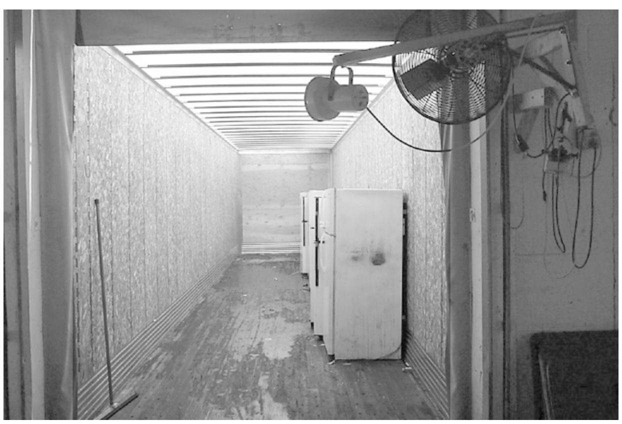
Conservation Services Group (CSG) bought Planergy's refrigerator recycling operation early in 2000. The main facility in Syracuse, New York, has been operational since 1991. These photos were taken on June 26, 2000. A crew of three can demanufacture more than 100 refrigerators in a day shift. In the first four years of the NYCHA/NYPA refrigerator replacement project, this facility demanufactured 65,038 units. Crews recovered 18,646 pounds of CFC-12 refrigerant, 277,767 pounds of aluminum, 49,882 pounds of copper, 11,115,600 pounds of steel, and 1,116,000 pounds of cardboard. Over that period, the cumulative energy savings from installing 81,212 new units was 45,600 MWh of electricity (561 kWh per refrigerator).

CSG recycling facility



Dennis Flack, Director of Operations

The Demanufacturing Process



1. Inside the delivery truck

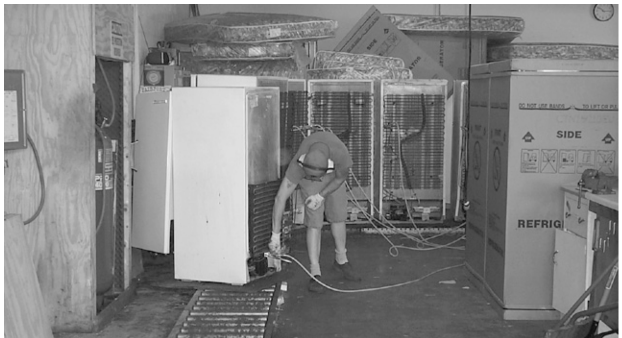
- 40-foot trailer can handle 100 old units
- Ceiling is translucent to supply natural light
- Cleanliness is a virtue; roaches infest many old units

2. At the head of assembly line

- Plywood flat used as ad hoc ramp
- Plywood supports fridge throughout demanufacturing process
- Rollers provide a guide and make life easy; six units can be moved with the push of a hand

Continued on next page

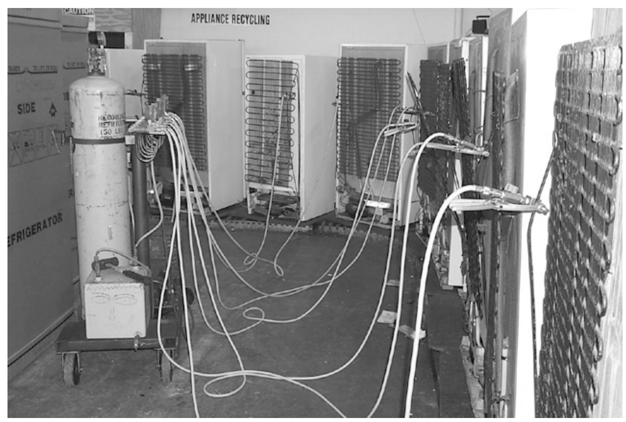
Figure 14: Demanufacturing old refrigerators: A photo essay *(continued)*



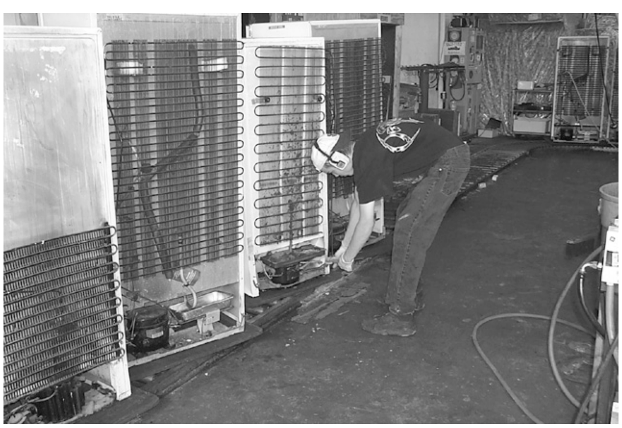
3. First stop: refrigerant extraction

Nifty tool extracts refrigerant

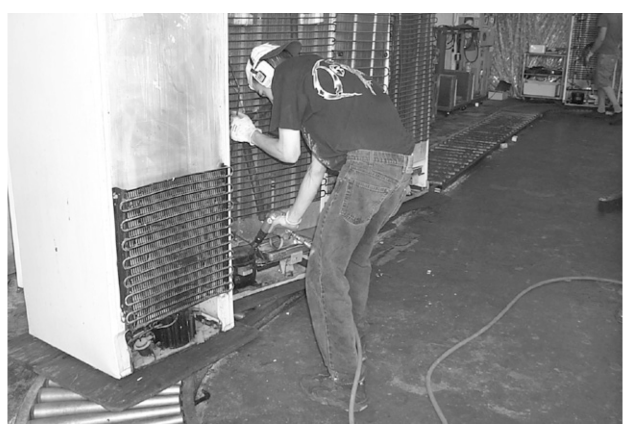
- Small-diameter pointed steel tube is inserted into copper
- Seals tightly
- Has "lock tight" action to hold on



4. Refrigerant extractor (does 10 at a time in about 12 minutes)



5. Snipping connections to compressor

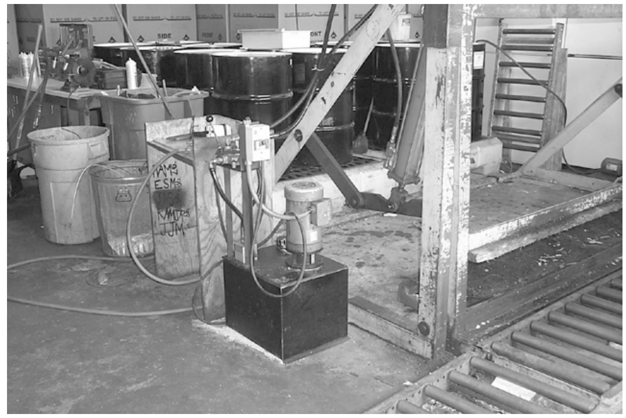


6. Blasting a hole into a compressor

Continued on next page

Figure 14: Demanufacturing old refrigerators: A photo essay *(continued)*

7. Oil-removal station


8. Hydraulic system for tipping refrigerators to drain oil


9. Tipping ’em over


10. Kicking back


11. Drip, drip goes the compressor oil

12. Oil is drained; on to the last stop

Continued on next page

Figure 14: Demanufacturing old refrigerators: A photo essay

13. A mining bar employed with a delicate touch separates plastic and aluminum from steel

14. Le coup de grace

15. The aluminum recuperation stomp

16. It was the best of times; it was the worst of times. . . .

Photos by Larry Kinney

Appendix: Watt-Hour Meters

Refrigerators have several modes of operation, so the amount of instantaneous energy use varies substantially. When the compressor runs (20 to 50 percent of the time), a typical residential refrigerator uses 100 to 180 watts. When doors open, lights come on, which draw from 20 to 80 watts. There are several fans, which are on for much of the time, and they draw 10 to 20 watts, as do small electric resistance heaters. The big hit is the defroster, of course; it draws 400 watts an average of 10 minutes or so per day, after which the compressor has to work overtime to remove the heat that the heater put into the refrigerator.

Whole-house watt-hour meters used by electric companies for billing purposes are inappropriate for measuring the consumption of individual refrigerators, but several companies have developed small digital energy meters that work well. Their features are summarized in **Table A-1**. **Figure A-1** shows photos of each energy meter described in the table.

Table A-1: Electric energy meters suitable for field testing of refrigerators

Some energy meters include a line cord hard-wired to the meter; others have a male plug on the back of the meter. If the line cord is hard-wired, the meter takes up more room in the tool box. Meters with a simple male plug can be plugged directly into a wall outlet if that's convenient, or fitted with a short extension cord, which can be stored with other auditing equipment.

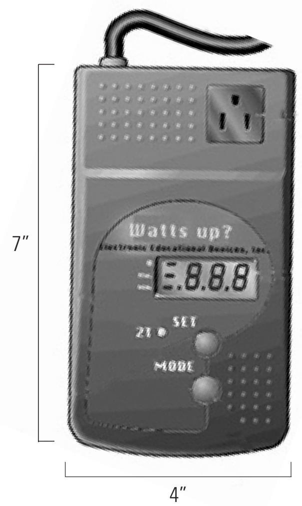
Supplier	Model	Cost ($)	Size	Weight	Principal features	Key advantages	Disadvantages
Watts Up Electronic Educational Devices Inc. 2345 South Lincoln Street Denver, CO 80210 tel 877-928-8701 www.doubleed.com	Watts Up	96	7" x 4" x 2"	24 oz	Displays power, energy, cumulative time, and cost of energy used.	Inexpensive, records elapsed time.	Only 5% accuracy, bulky, and has line cord hard connected.
The Watt Stopper 2800 De La Cruz Boulevard Santa Clara, CA 95050 tel 800-879-8585 www.wattstopper.com	PL-100 Plug Load Analyzer	120	5.4" x 3.5" x 1.7"	9 oz	Displays voltage, current, power, apparent power, power factor, minimum and maximum current and power, true energy usage, and total elapsed time to the second.	Special price for weatherization, measures many parameters, easy to use (one-button operation), very accurate, and small package.	Like all others, doesn't indicate defrost cycle. New model will include this feature.
Brand Electronics 421 Hilton Road Whitefield, ME 04353 tel 888-433-6600 www.brandelectronics.com	4-1850	150	5" x 5" x 2.25"	16 oz	Displays power, energy, total elapsed time (in hours and tenths), and cost per month.	High sampling rate yields good accuracy, easy to use.	Has line cord hard connected.
Optimum Energy Products Ltd.[a] Suite 236, 16 Midlake Boulevard S.E. Calgary, Alberta, Canada T2X 2X7 tel 877-256-3431 www.electricitymetering.com	EML 2000	219	6" x 2" x 4"	15 oz	Displays voltage, power, energy, total elapsed time in hours and minutes, and costs of energy used in dollars.	Can do two channels at a time and 240-VAC as well as 120-VAC. Projects costs, which may be helpful for energy education.	Requires clipping onto a current loop and using a wall transformer.
Line Logger Pacific Science & Technology Inc. 64 N.W. Franklin Avenue Bend, OR 97701 tel 800-388-0770 www.pacscitech.com	Line Logger	249	4.5" x 2.5" x 1.5"	8 oz	Displays voltage, power, and energy. Uses a single knob to switch between displays and to reset energy consumption to zero.	Very small and light, and simple to operate. Price break to $229 each for orders of more than five units.	Doesn't record elapsed time, so computing annual appliance use is complicated; pricey for features.

Notes: a. Optimal Energy's EML 2000 is manufactured by Brultech Research Inc. under the model number ECM 1200. Brultech may be contacted at 12L67 Harbourview Road, Port Colborne, Ontario, Canada, L3K 5V4, tel 905-834-7559, www.brultech.com.

To test energy consumption with a watt-hour meter, note the exact time, and set the kWh register to zero. At the end of the test run, note energy used in kWh and time. Then estimate annual performance by multiplying the reading by 8,766 (the number of hours in an average year) and dividing the result by the elapsed time of the test in hours expressed as a decimal. If the refrigerator is frost-free and no defrost period occurred over the measurement interval, the result should be multiplied by 1.08.

Figure A-1: Photos of five energy meters

Electronic Educational Devices
Model: Watts Up

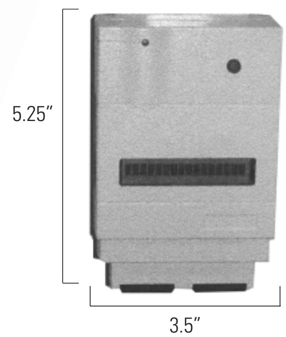


Courtesy Electronic Educational Devices Inc.

Optimal Energy Products Ltd.
Model: EML 2000

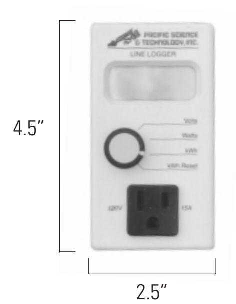
Courtesy Optimum Energy Products Ltd.

The Watt Stopper
Model: PL100 Plugload Analyzer



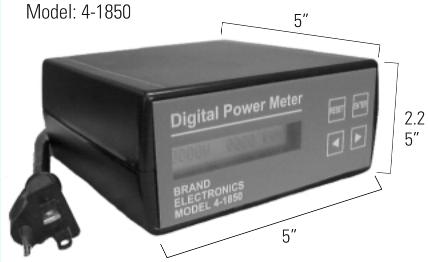
Courtesy Larry Kinney

Pacific Science & Technology Inc.
Model: Line Logger



Courtesy Larry Kinney

Brand Electronics
Model: 4-1850



Courtesy Brand Electronics

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Dr. **Larry Kinney** is a research manager with the E SOURCE technology assessment group, which analyzes energy efficiency and emerging energy technologies. With an academic background in physics and philosophy, Larry has been active in energy-related research and development for almost 30 years. He has broad experience in weatherization program operations, energy-efficient refrigeration, lighting and daylighting technologies, air-handling and conditioning systems, and controls. Larry also has a background in energy-efficiency program evaluation, from instrumentation design and analysis to program policy research. Before joining E SOURCE, he was the president of the Synertech Systems Corp., an energy systems research, development, and demonstration firm in Syracuse, New York. Prior to founding Synertech in 1983, he was a senior research fellow with the Syracuse Research Corp., where he co-founded and directed the corporation's Energy Research Center.

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