New York Power Authority/ New York City Housing Authority Refrigerator Replacement Program

First Program Year Evaluation

Final Report 97-12
August 1997

New York State
Energy Research and Development Authority

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NEW YORK POWER AUTHORITY/ NEW YORK CITY HOUSING AUTHORITY REFRIGERATOR REPLACEMENT PROGRAM

First Program Year Evaluation

Final Report

Prepared for

THE NEW YORK STATE
ENERGY RESEARCH AND DEVELOPMENT AUTHORITY

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NOTICE

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A NYSERDA Report in Brief

Report: New York Power Authority/New York City Housing Authority Refrigerator Replacement Program - First Year Evaluation Report 97-12

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Background: This report presents the results of a major initiative aimed at replacing 180,000 old, inefficient refrigerators in apartments managed by the New York City Housing Authority. The report quantifies the energy performance and savings achieved during the first year of the multi-year program spearheaded by the New York Power Authority. Using bulk purchasing as an incentive to appliance manufacturers to produce energy-efficient, apartment-size refrigerators, a total of 20,000 14.4 cubic foot refrigerators were manufactured by General Electric and installed by Planergy, Inc., during the first year of the program.

Objectives: The project's objective was to provide program planning support and third-party evaluation of the New York Power Authority (NYPA)/New York City Housing Authority refrigerator replacement program.

R&D Results: The energy performance of a sample of both old and new refrigerators was measured in the field and in an environmental test chamber built for the purpose at Synertech Systems Corporation's offices. Two data loggers were used in testing: a sensitive watt hour meter, supplemented by spot checks of ambient and refrigerator temperature, and an Il-channel data loger designed specifically to measure a number of parameters associated with refrigerator use and performance. A total of 276 tests were conducted of refrigertors in the field -- 220 on existing refrigerators before replacement, and 56 on the newly-installed General Electric units. In addition, a number of tests were conducted on both old and new units in the test chamber.

Taking into account ambient temperatures for old and new units and assuming that all refrigerator controls were set at 2, the project would have averaged savings of 643 kWh per year per refrigerator replaced, a savings of 53.4 percent. Based on NYPA energy costs of 3.54 cents per kWh, this yields an average savings for energy of $22.78 per unit replaced. Demand savings, however, add $20.91 for a total of $43.71 per unit replaced per year. However, with the blend of control settings, overall project savings were 578 kWh per year, yielding a dollar savings of $39.25. With 20,000 refrigerators replaced during the program's first year, annual savings should be $785,000. Many of the older refrigerators were smaller than the replacement model. If the consumption of the replaced units were scaled with volume to be compatible with the 14.4 cubic foot new unit, the savings would be 728 kWh per year.

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ABSTRACT

Acting as an energy services provider, the New York Power Authority (NYPA) has initiated a long-term project through which 20,000 refrigerators per year will be replaced with the most energy-efficient units possible in apartments managed by the New York City Housing Authority (NYCHA). Using bulk purchasing as an incentive to appliance manufacturers to produce energy-efficient refrigerators suitable for use in apartments, 20,000 14.4-cubic-foot refrigerators manufactured by the General Electric Company were replaced in the first year of the program, which ended in December 1996. These units, which have a label rating of 499 kWh per year, achieved a savings of 47.9 percent, or 578 kWh per year. Savings were determined by field testing and laboratory testing of 220 existing refrigerators and 56 newly-installed units. In the next program year, a 15.0-cubic-foot Maytag refrigerator, newly-designed in response to bulk purchasing incentives, is being installed. The new unit has a label rating of 437 kWh per year, 31 percent better than 1993 energy standards.

Old refrigerators removed from apartments are "demanufactured" in an environmentally-appropriate way and both metals and refrigerants are recovered for reuse.

Key Words: Refrigerator, energy efficiency, savings evaluation, recycling, market transformation

ACKNOWLEDGMENTS

The process of measuring refrigerator performance in New York City apartments and in a Syracuse test chamber—and then making sense of the results—has been challenging but rewarding. A number of people played important roles in helping the evaluation to be successful.

The members and auxiliary members of the Project Advisory Committee were critical in formulating the evaluation plan, aiding the process in the field, and assessing project findings. Bill Steinmann of the New York City Housing Authority (NYCHA) sustained the vision of energy-efficient refrigerators in NYCHA apartments, and he and his staff supported the needs of the evaluation project at every turn. Special thanks are due to Scott Brown and Dominick Luce of the New York Power Authority for their effective management of advisory committee meetings and help in gathering data and providing insights beyond the numbers.

Dennis Flack of Planergy was a very useful source of practical wisdom in all matters associated with refrigerator performance. Members of his staff delivered a great number of old refrigerators to Synertech's test chamber and were cheerful about recycling the units after testing.

Rob Pratt and Jim Miller of the Pacific Northwest Laboratory provided valuable insights into planning and data analysis and are the principal authors of the sections of the final report on quantitative methodologies and findings. All involved in the project are grateful for the support of their excellent work provided by the Department of Energy's Office of Energy Efficiency and Renewable Energy. DOE's project officer, Margaret Dwyer, was a active member of the Project Advisory Committee.

Synertech particularly appreciates the support of an independent evaluation of this large-scale refrigerator-replacement project by the New York State Energy Research and Development Authority. Norine Karins provided steady guidance, helpful criticism, and a good sense of balance throughout the project.

Finally, the project benefited from the willingness of hundreds of residents of NYCHA apartment buildings to allow Synertech technicians to attach data loggers to their refrigerators for extended periods in spite of occasional inconvenience. Their cooperation was a necessary condition for the project and the good humor and patience displayed by most residents was especially welcome.

Laurence F. Kinney
Syracuse, June, 1997

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SUMMARY

This report documents principal project activities and energy savings achieved in the first year of a large-scale refrigerator replacement project in New York City. In the role of energy services provider, the New York Power Authority (NYPA) conducted a project through which 20,000 high-efficiency refrigerators replaced old, less-efficient refrigerators in apartments managed by the New York City Housing Authority (NYCHA). This was the first program year of a multi-year program which calls for replacing 20,000 refrigerators per year using new refrigerators that are as close to state-of-the-art in energy efficiency as practical. Under an arrangement between NYPA and NYCHA, and with approval of the U.S. Department of Housing and Urban Development (HUD), NYPA provides funds, procures units, manages installation and removal, and provides for recycling the units removed. NYPA's investment is to be repaid over a ten-year period from the stream of expected savings in electric energy and demand costs.

The American appliance manufacturing industry has not concentrated on producing energy-efficient refrigerators for apartments. Bulk purchasing power was used in this project to change the market. With the promise of large-scale sales of apartment-size refrigerators, NYPA developed a request for proposals (RFP) to provide, during the program's first year, 14-cubic-foot units that would be 30 percent more energy-efficient than required by 1993 appliance energy standards. NYPA would then require progressively more energy-efficient units in the years to follow. Although no manufacturer agreed to meet the specifications, a revised RFP yielded satisfactory results. In the first year of the program, a 14.4-cubic-foot unit manufactured by the General Electric Company was procured. The unit had a DOE test rating of 498 kilowatt hours per year (kWh/yr) and was bought at a favorable price. The rated energy consumption was 20 percent better than the 1993 standards.

Later, Maytag agreed to produce a slightly larger and more efficient unit (15.0 cubic feet, 437 kWh/yr, 31 percent better than 1993 standards). This unit became available for testing in early 1997 and is being installed in the second program year.

Extensive program planning, along with the implementation of management practices that streamlined logistics and communications, resulted in a remarkably smooth first year of operation. Large trucks from a GE warehouse in Maryland would deliver 70 to 120 new refrigerators to the designated site in New York City by 7 a.m., and by mid-afternoon the new units would be installed, old ones loaded for transport to the recycling facility, and paperwork finished. In spite of a major snowstorm that delayed work for nine days in January 1996--only a week after the program started--first year project goals were achieved by mid-December. No production days were missed, very few units were damaged in shipment, and only a single refrigerator was reported stolen. Eighty percent of the old refrigerators removed from NYCHA apartments were recycled by Planergy of New York in an environmentally-appropriate fashion, and substantial quantities of metals and refrigerant gas were recovered for reuse. The small number of refrigerators not recycled were relatively newer units in fairly good condition. They were placed in storage for potential use as replacements in apartment buildings not yet included in the NYPA program.

The New York State Energy Research and Development Authority (NYSERDA) sponsored Synertech Systems Corporation's program support and evaluation services. In addition, the U.S. Department of Energy (DOE) supported Pacific Northwest National Laboratory's analytical and oversight work. The present report was a team effort by members of both organizations.

An advisory committee, composed of representatives from each of the above-mentioned organizations as well as from the Consortium for Energy Efficiency, was formed to plan and review project progress and to help troubleshoot problems as necessary. Handouts and slides were prepared for regular meetings of the advisory committee; these, along with the discussions which ensued, substantially aided overall communications among participants.

In order to assess actual energy saved and analyze program costs and benefits, the energy performance of a sample of both old and new refrigerators was measured in the field and in an environmental test chamber built for the purpose at Synertech's offices. Two data loggers were used in testing: a sensitive watt hour meter (the W-120) supplemented by spot checks of ambient and refrigerator temperature, and an 11-channel data logger (the R-100) designed specifically to measure a number of parameters associated with refrigerator use and performance. A total of 276 tests were conducted of refrigerators in the field--220 on existing refrigerators before replacement and 56 on the newly-installed GE units. In addition, a number of tests were conducted on both old and new units in the test chamber.

The energy consumption of refrigerators depends heavily on the difference in temperature between their fresh food and freezer compartments on the one hand and the surrounding ambient air on the other. High consumption results when apartment temperatures are elevated or when refrigerator controls are set high. New York City apartments tend to be quite warm; best available information suggests that their annual average temperature is 78.7°F. Testing showed that leaving controls of the new GE refrigerator at their mid-level (5 of 9), as delivered from the factory, resulted in quite cold freezer and fresh food compartment temperatures and energy consumption well above DOE label ratings. Adjusting the controls downward to 2 maintained temperatures at appropriate levels and resulted in average energy consumption of about 563 kWh/yr, 13 percent above label rating. This level of energy consumption above the label rating was likely due to warm apartment temperatures, a condition which has a greater absolute energy consumption effect on older refrigerators than newer ones.

After discovering the unnecessarily high factory setting, controls on new units were reset to 2 on installation and residents were given a handout explaining the advantages of maintaining the control at 2. NYCHA staff also revisited the refrigerators installed at the outset of the program to reset their controls to 2. Of course, some residents adjusted their controls to a less energy-efficient setting. A survey showed that 65 percent of the refrigerators have a control setting of 2, and 35 percent at 5. (See Table 5-2 for full results and extrapolations from other settings.)

Taking into account ambient temperatures for old and new units and assuming that all controls were set at 2, the project would have averaged savings of 643 kWh per year per refrigerator replaced, a savings of 53.4 percent. Based on NYPA energy costs of only 3.54 cents per kWh, this yields an average savings for energy of $22.78 per unit replaced. Demand savings, however, add $20.91 for a total of $43.71 per unit replaced per year. However, with the blend of control settings, overall project savings were 578 kWh per year, yielding a dollar savings of $39.25.

With 20,000 refrigerators replaced in the first year, annual savings should be $785,000.

Many of the older refrigerators were smaller than the new ones installed. If the consumption of the replaced units were scaled with volume to be compatible with the 14.4-cubic-foot new refrigerators, the savings would be 728 kWh per year.
Another resident benefit is that the new refrigerators have automatic defrost, a feature missing from most of the units removed.

It is concluded that the program is a success and will likely achieve even better cost effectiveness in coming years. The learning curve has been traversed and management systems are in place that will ensure continued good production. Evaluation of actual savings should continue, particularly because the Maytag unit is a new design. Low-cost monitors that track temperature as well as energy should be used.

Section 1
INTRODUCTION

BACKGROUND AND PROJECT ORIGINS

Energy-efficiency standards for refrigerators adopted by the U. S. DOE in conjunction with a regulatory ban on chlorofluorocarbons (CFCs) have had near-revolutionary effects on the refrigerator manufacturing industry and its products in this country (Turiel and Hakim 1996). Many manufacturers have very substantially retooled to meet the standards, and by the same stroke have automated many of the steps in the manufacturing process. In consequence, new refrigerators cost approximately the same as those manufactured before efficiency standards were adopted, yet their consumption of energy has decreased by more than half.

Figure 1-1 plots energy consumption of a sample of 1989 model refrigerators and those manufactured under 1991 and 1993 standards. Refrigerators manufactured in the mid- to late-1970s tended to be substantially less efficient than the 1989 models.

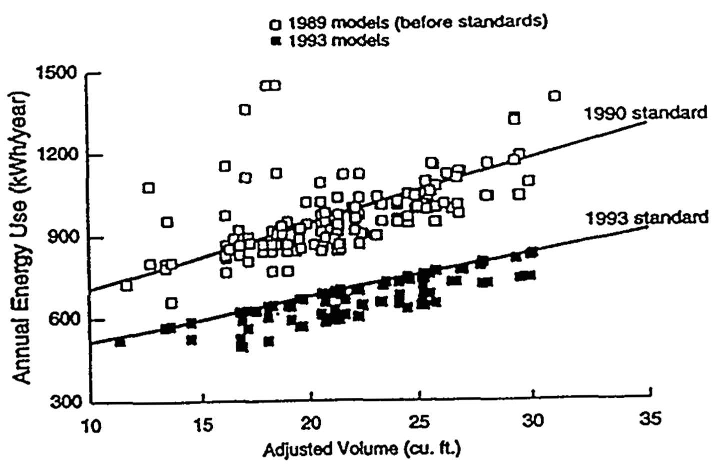

Figure 1-1. The effect of 1991 and 1993 refrigerator standards on a sample of 1989 and 1993 model refrigerators. "Adjusted volume" on the x-axis is sum of the fresh food volume and 1.63 times the freezer volume. (From *From the Lab to the Marketplace, Making America's Buildings More Energy Efficient*, Lawrence Berkeley Laboratory, 1995, quoted in Turiel and Hakim [1996].)

The NYPA supplies electric energy to the 2,900 buildings managed by the NYCHA at a price that is substantially lower than the rates of Consolidated Edison, the other major utility in the New York City area. Under an electricity supply agreement between NYCHA and NYPA formed in 1995, NYPA agreed to invest $38 million to implement various energy-conservation measures in NYCHA buildings in the role of energy services provider. Most of the 180,000 apartments in NYCHA's buildings have older refrigerators which waste electricity and require manual defrosting, or both. These refrigerators typically have 12 or 14 cubic feet of combined cooler and freezer volume. Since very energy-efficient 14-cubic-foot refrigerators were becoming available, NYPA and NYCHA managers decided that replacing the stock of existing energy-inefficient refrigerators would be a cost-effective conservation measure.

In a joint effort involving many organizations, virtually all of the 180,000 refrigerators are being replaced with the most energy-efficient self-defrosting refrigerator/freezers available at the time of replacement. A commitment has been made for changing out 20,000 units per year over a four-year period, and plans are being made to change out all refrigerators over a nine-year period, beginning with the oldest units. The process of bulk purchasing is key to ensuring both good energy efficiency and low price (Brown and Wisniewski 1996).

This report covers the planning, execution, program support, and evaluation of the first year of the program, which successfully completed the purchase of 20,000 refrigerators between January 4 and December 19, 1996, and the recycling of almost 16,000 units.

ORGANIZATIONAL PARTICIPANTS AND SPONSORS

In addition to NYCHA and NYPA, the U.S. Departments of Housing and Urban Development and Energy are playing important roles in the project. HUD helps pay NYCHA's energy costs and both DOE and HUD are actively urging public housing authorities to undertake energy conservation measures through the mechanism of performance contracting,[1] which allows public housing authorities to forge contracts with energy services companies and keep the savings. The NYPA-NYCHA project was the first refrigerator replacement project undertaken via this DOE-HUD initiative. Accordingly, there is strong interest in quantifying actual savings achieved.

Planergy, a recycling company retained by NYPA, "demanufactures" the old refrigerators. Potential pollutants are separated and dealt with in an environmentally-safe way. Metals are recovered for other uses.

The New York State Energy Research and Development Authority (NYSERDA) is sponsoring the Synertech Systems Corporation's evaluation and support work for the program. In addition, DOE is sponsoring Pacific Northwest National Laboratory's provision of two workers for the analytical portions of the evaluation. Through the Consortium for Energy Efficiency of Boston and other organizations, DOE is promoting refrigerator replacement and related energy conservation projects across the country.

EVALUATION AND PROGRAM SUPPORT PLAN

A detailed evaluation and program support plan was drafted, circulated to a project advisory committee consisting of representatives of the organizations listed above, and revised in light of feedback received. The revised plan is provided as Appendix B of this report. It contains an extensive discussion of the refrigerator replacement program background.

As discussed in the plan, the fundamental objective was to develop accurate, defensible, average annual savings estimates for the high-efficiency replacement refrigerators relative to the displaced models, bounded by known and reasonable levels of uncertainty.

[1] The legislative mandate for these conservation activities is the federal Housing and Community Development Act of 1987. See "Energy Performance Contracting for Public and Indian Housing: A Guide for Participants" by a team from the Energy Division of the Oak Ridge National Laboratory, 1992.

Toward this end, it was decided to measure the performance of a one percent sample (200) of existing refrigerators in the field, using a precise watt-hour meter developed by Synertech known as the "W-120," with a data collection protocol that included gathering information on refrigerators tested, including control settings, food loading, ambient temperature, and temperatures in the fresh food and freezer compartments of the refrigerator. In addition, the R-100, an 11-channel data logger developed by Synertech to test refrigerator performance as a function of a number of relevant variables, was used to monitor 20 existing refrigerators. Fifty-six new refrigerators were also tested in the field, ten of them with the R-100, the remainder with the W-120. Finally, a number of tests were run in Synertech's refrigerator test chamber, where precise control over environmental conditions could be maintained.

The field monitoring activities outlined above describe a multi-faceted approach to estimating the savings in electrical energy and demand from the project. Fundamentally, this approach involved:

- Short-term metering of *in situ* loads on a sample of each principal model of existing refrigerator and for the high-efficiency replacement refrigerators for a duration of approximately one week (the W-120 data);

- Collecting snapshot data (at the beginning and end of the metering period) of key drivers for load, including room temperature, control settings, refrigerator compartment temperatures, and food loadings;

- Complementing the W-120 consumption data with much more detailed metering using R-100 data loggers to collect 15-minute interval data, including ambient air, refrigerator and freezer compartment temperatures, door openings and durations, defrost cycles, etc.;

- Using R-100 data loggers and a controlled-environment test chamber to provide DOE label rating tests for the principal refrigerator models, to investigate the nature of outliers from the field data, and to determine the effect of key behavioral components of refrigerator consumption, especially ambient and compartment temperature relationships.

The subsequent analysis involved:

- Adjusting the short-term W-120 data for the pattern of indoor temperatures experienced over the year;
- Developing average savings estimates for each model replaced;
- Accounting for the persistence of savings over time;

- Accounting for heating and cooling interactions, if any; and
- Verifying that the replacement refrigerators performed as specified by the manufacturer.

Section 2 covers principal project activities. Sections 3 , 4, and 5 discuss analytical issues and present findings. Conclusions and recommendations are presented in Section 6.

Section 2

PROGRAM IMPLEMENTATION

BULK PURCHASES

There is strong interest on the part of forward-looking utilities and other organizations interested in achieving energy efficiency in programs that replace inefficient refrigerators with efficient ones. The reason is that the stakes are large. About one quadrillion Btu per year, over one percent of our nation's total energy consumption, would be saved if American refrigerators were reduced from an average consumption of 1200 kWh/yr to 400 kWh/yr[1]. There are a lot of refrigerators in our homes--about 120 million that are plugged in 24 hours a day--and it is technically feasible to produce refrigerators that are at least three times more efficient that those produced by the large manufacturers only eight years ago. For the past 15 years Sunfrost, a small California manufacturer, has produced very efficient refrigerators that are better than the proposed 1998 standards. And actuality entails possibility, as Aristotle pointed out. But how can large manufacturers be influenced to produce genuinely energy-efficient refrigerators? Or, from a different perspective, how can the marketplace be changed?

These questions are complex, of course, but three principal ingredients in the mix of answers are particularly instructive. The first is the development of standards of energy efficiency and their promulgation by the DOE in conjunction with a ban on CFC-based refrigerants by the U.S. Environmental Protection Agency (EPA). Papers by the team of researchers from Lawrence Berkeley Laboratory principally responsible for developing these standards offer fascinating documentation of the technical and political processes associated with adopting standards, along with the various effects in the marketplace, virtually all of which are positive (see Turiel et al 1990; Turiel and Hakim 1996).

[1] This computation makes the usual assumption that a kWh saved at the plug is equivalent to 10,000 Btus saved at the power plant, owing to the Carnot effect and other inefficiencies from fuel to plug.

A second major effort at influencing a radical change in the marketplace was the Super Efficient Refrigerator Program (SERP) (L'Ecuyer et al 1992; Feist et al 1994). Through their demand-side management programs, a consortium of 30 utilities put together a $30-million "golden carrot" that was awarded to the refrigerator manufacturer which produced the most energy-efficient refrigerator at least 30 percent below 1993 standards and was also free of CFCs. The Whirlpool Corporation won the SERP award with a 22-cubic-foot unit featuring an ice-maker and cold-water dispenser. In addition to Whirlpool's manufacturing of this unit, there is evidence that a good deal of engineering work was accomplished by other companies in competing for the award that is having positive influences on refrigerator design throughout the industry.

The present project represents a third major approach to influencing radical changes in the marketplace. No fewer than three papers presented at the 1996 American Council for an Energy-Efficient Economy (ACEEE) Summer Study on Energy Efficiency in Buildings covered elements of NYPA's bulk purchase work (Brown and Wisniewski 1996; Nolden and Morgan 1996; and Suozzo and Nadel 1996). The full-featured Whirlpool 22-cubic-foot SERP unit is energy-efficient, but it is larger than necessary for apartments, and more costly. There is need for a smaller, less-expensive, very efficient unit. Since public housing authorities buy a great number of refrigerators each year, it is reasonable to suppose that influence over not only the price but also the performance of refrigerators might flow from cleverly-executed bulk-purchase agreements between buyers and manufacturers.

With help from NYCHA, DOE, HUD, the Consortium for Energy Efficiency, and the Citizens' Conservation Corporation, NYPA managed just that. The process involved developing a Request for Proposal (RFP) for a CFC-free, 14-cubic-foot, auto-defrost refrigerator-freezer 30 percent more energy-efficient than 1993 standards by 1997, then 40 percent more efficient by 1998, and 50 percent more efficient by 1999.[2] Another

[2] The 1993 standard for this unit states that the annual energy use according to the "DOE test" must be less than 16.0 AV + 355 kWh/yr. The standard is stated as a function of the "adjusted volume" of the unit, where AV is the sum of the volume of the fresh food compartment and 1.63 times the volume of the freezer compartment. The "DOE test" for refrigerator-freezer units with an automatic defrost system requires that

constraint was width: in many NYCHA apartments, the space for refrigerators is limited to 28 inches in width.

In response to the initial RFP in the summer of 1995, Maytag was the only company willing to commit to the initial energy-efficiency standard, and its units were to be an inch too wide and a year too late for the proposed beginning of the program, December 1995. Other bidders on this initial RFP would not meet the energy-efficiency goal. (None of the manufacturers would commit to the subsequent-year standards.) Accordingly, a revised RFP was produced in August 1995 which did not address the long-term future. The revised RFP envisioned NYPA exercising the option of choosing more than one supplier.

The result was selection of the General Electric bid for the first year of the program. GE's 14.4-cubic-foot unit met all bid specifications except energy performance. The GE unit had a DOE rating of 498 kWh/yr, which is 20 percent better than the 1993 standard for refrigerators of its size and product class, 620 kWh/yr. NYPA purchased 20,001 of the GE units in 1996.

A 15.0-cubic-foot Maytag unit rated at 437 kWh/yr. would be provided for the subsequent year(s). Maytag's revised bid yielded a unit 27.5 inches wide that is rated to use 31 percent less energy than 1993 standards and is attractively priced. As of March 1997, 100 of the Maytag units had been field tested, and production has begun of the 20,000 to be installed in NYCHA apartments in 1997.

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a unit be run with controls at their mid-point, with no food load and with no door openings, in a test chamber at 90°F until the unit under test reaches steady-state conditions. Measurement of energy consumed is then taken from a given point in the defrost cycle (e.g., its beginning) to the corresponding point in the following defrost cycle. This typically corresponds to 12 to 14 hours of compressor run time. A second test is then run at a (usually lower) control setting that allows the freezer to run at 5°F or warmer. The results of these tests are mathematically adjusted to produce an estimate of the consumption as if the freezer were running at 5°F and the refrigerator at 45°F or cooler. The kWh consumed over this period is then normalized to a 365-day year. If the unit has an anti-sweat switch, this pair of tests is run with the anti- sweat switch "on" for one set and "off" for a second set, and the results are averaged. 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." See the *Federal Register* of August 10, 1982, pp. 34517-34529.

Maytag implemented an entire new manufacturing system termed "advanced design process (ADP)" for designing and producing this 15-cubic-foot unit and, not surprisingly, many housing authorities are trying to procure the energy-efficient units offered at such an attractive price. In short, the bulk purchasing process had a very positive influence, and Maytag is enjoying a heavy demand for its apartment-size refrigerator. It remains to be seen if other manufacturers will try to compete with Maytag's price and energy-efficiency.

PROJECT COORDINATION AND MANAGEMENT

Much of the project planning and agreements between the two key parties is reflected in a formal document called a Customer Installation Commitment (CIC). Fundamentally, the CIC is a contractual agreement between NYPA and NYCHA that reflects the work NYPA commits to as an energy services provider and the utility bill savings NYCHA should expect by virtue of lower costs of energy. The document also specifies a ten-year repayment schedule at 6 percent interest that reflects the actual cost of equipment installed .

The first CIC agreement, covering 2,090 refrigerators installed in the Edenwald apartment complex in the Bronx, was signed by both parties on December 29, 1995. In addition to six pages on the main elements of the agreement between the two parties, it contained appendices that include details on the new refrigerator (specifications, maintenance, and warranty), information on rates and billing, and the complete evaluation plan.

In practice, new CICs are produced and signed as the project progresses from refrigerator replacements in one block of buildings to another. As more data on refrigerator performance (old and new) become available, details of paybacks included in CICs are changed to reflect actual savings. Thus, CICs serve as formal contractual arrangements, management tools, and evaluation records.

As part of the planning and management process, an advisory committee was formed that met in NYPA's offices approximately every other month throughout the first year of the project. This committee, composed principally of program staff of NYPA and NYCHA, also included representatives of the Consortium for Energy Efficiency, General Electric, NYSERDA, Pacific Northwest National Laboratory, Planergy, Synertech, and U.S. DOE.

In early meetings topics principally covered logistical matters, coordination between people in the field, and the development of CICs, evaluation plans, and brochures. Program policy options were discussed, drafts of documents were circulated for comment, and final versions reflective of useful suggestions were produced. For example, the evaluation project plan in Appendix B and the resident brochure reproduced in Appendix C benefited from animated discussions with and helpful suggestions from the advisory committee.

As the program progressed through the first year, meetings focused on production issues and results of field and testing chamber tests. In addition, throughout the project a "Refrigerator Program Status Report" was produced by Dominick Luce of NYPA's staff. This document and attachments became a compendium of all information on the program and revised versions became the major handout at each advisory committee meeting. Since it contained agendas and notes on each project committee and field meeting, documented concerns and resolutions, and included spread sheets that tracked every day's activity (by site, organization, and refrigerator), this document served as a very effective management tool.

THE INSTALLATION PROCESS

During normal operations in year one of the program, the day began at 3 a.m. for two truck drivers at GE's large regional distribution warehouse in Maryland. The new refrigerators were manufactured in Alabama and shipped to the warehouse as a convenient staging ground for customers in the Northeast. It took a good four hours to drive an 18-wheeler from the warehouse to an apartment complex in New York City; and an early start helped avoid heavy commuter traffic. A full load contained 72 units and the day's schedule usually required a second truck with a partial load.

Planergy's subcontractor, Howard Siskind, and workers met the GE trucks promptly at 7 a.m. They removed refrigerators from the partially-loaded truck first. They uncrated them, marked each unit with the apartment number where it would be installed, and saved the crating material for Planergy's recycling truck that arrived on site between 10 a.m. and 1 p.m.

Meanwhile, members of NYCHA's staff acquainted with residents knocked on apartment doors, beginning on the building's top floor. Residents had been prepared for the arrival of their new refrigerators by previous verbal announcements by the NYCHA staff, who also gave them copies of the brochure beforehand, and by posters on the information boards in their building lobbies. Planergy's subcontractors removed the old units and installed the new ones, organizing work so that the work elevators would carry new refrigerators on the ascent and old ones on the descent.

Access and use of elevators is a critical path in the process. By starting early, the workers can finish before school children arrive home around 3 p.m., which ties up elevators.

At the beginning of the program, controls were set as they came from the factory, 5 on a scale of 9. (The GE unit does not have an anti-sweat switch or customer-accessible freezer controls.) However, when it was discovered in chamber testing at Synertech that the units ran quite cold at this setting (-4°F in the freezer compartment) and consumed substantially more energy than the label rating, the decision was made to reset the control at 2 during installation. This maintained the freezer at 5°F and the fresh food compartment in the low 40s, the effective setting of the standard DOE test. Later, NYPA developed a simple-to-read handout to explain the importance of the lower setting, and this was distributed to all families receiving new refrigerators.

NYCHA personnel examined the old refrigerators as they were removed, storing those in best condition. These stored units may be used to replace failed units in apartment complexes not yet served by the replacement program. Typically, 80 percent or more of the refrigerators removed were judged to be too old or deteriorated to save and were loaded on the recycle truck.

As shown in Table 2-1, 20,001 new refrigerators were purchased in year one of the program and 15,939 old units were recycled as of December 19, 1996. The installation process is shown in Photos 2-1 to 2-5.

THE RECYCLING PROCESS

The 18-wheel recycling truck could handle 80 to 105 old refrigerators, along with packing material from the new units. The truck was driven to Planergy's recycling facility in Syracuse, NY, a 5- to 6-hour trip. The truck was usually left at the loading dock in the middle of the night, but sometimes arrived between 6 and 7 a.m.

Except on the rare occasions of the tardy arrival of the truck, recycling began promptly at 5 a.m., or earlier. The very efficient and surprisingly clean process was facilitated by the clever design of a "disassembly line" and a number of special tools devised by Dennis Flack, Director of Planergy's New York operations. As shown in the Photos 2-6 to 2-9, the process began close to the loading docks, where refrigerators were put in a line on squares of plywood placed on industrial rollers. The line of rollers snaked around the floor from station to station, ending back near the loading dock area again. By means of the rollers, a whole line of refrigerators could be moved with only a gentle push.

A special tool was used to penetrate, clamp, and seal refrigerant lines to facilitate the extraction of refrigerant gas, typically R-12. The gas was stored in 125 pound cylinders strapped together on a wheeled cart. This design allowed technicians to evacuate refrigerant from up to ten refrigerators at a time. Next, holes were punched into the top

Table 2-1. Program Year 1996 Summary.

Total purchased by NYPA	20,001
Total delivered to NYCHA	20,000
Note: One unit was stolen.	
Total installed in apartments	17,213
Total in storage	2,787
Total recycled	15,939
Total damages by GE	29
Total damages by contractor	0
Total claims for resident property damage	4
Note: Claims totaled less than $300.	
Total work days available in 1996	247
Total used	217
Total lost	9
Note: The 9 days were lost due to	
a January, 1996 snow storm.	
Total missed by contractor	0
Total ahead of schedule	18
Total not scheduled	3
Average installed per day	92
Total days GE truck late	5
Total days GE truck amount incorrect	4
Total days GE truck did not show up	0
Most installed in apartments in a day	112
Most handled in one day	142
Most recycled in one day	108
Total tested	276
Old	220
New	56
Total NYCHA developments covered	28

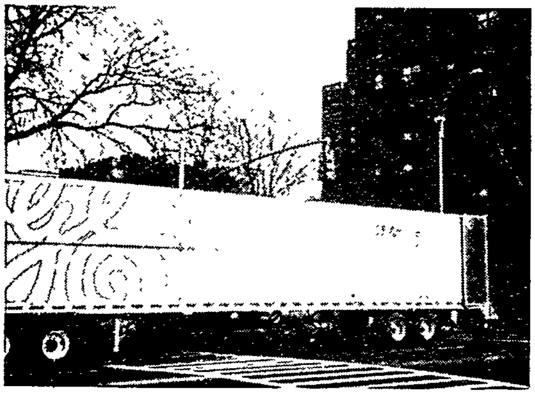

Photo 2-1. GE's delivery truck.

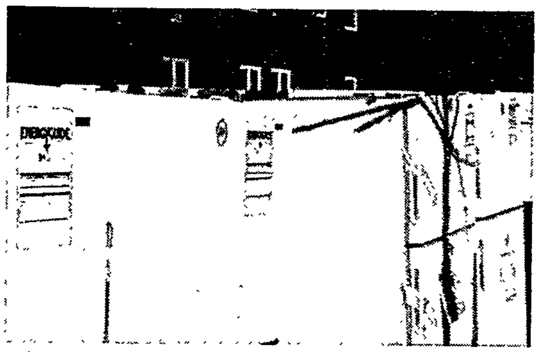

Photo 2-2. New units uncrated. The energy guide says "$41 per year."

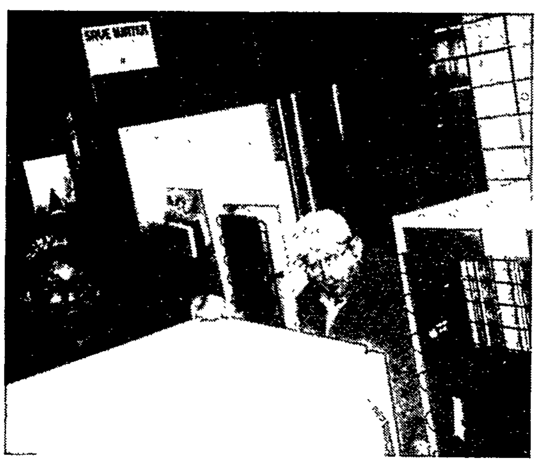

Photo 2-3. Wholesale changing of refrigerators means a crowded lobby and high elevator usage for a few hours.

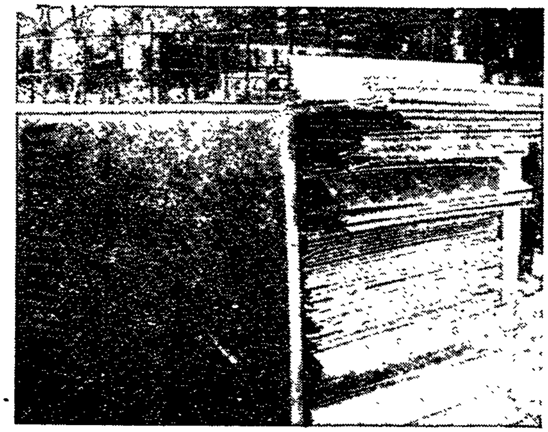

Photo 2-4. Packing materials ready for recycling.

Photo 2-5. Loading the recycling truck for the trip to Syracuse.

rear of the compressor housings in anticipation of draining the oil they contained. As shown in Photo 2-9, three refrigerators at a time were tipped over at the oil-draining station. Toward the end of the recycling process, the insides of the refrigerators were removed, and copper, aluminum, plastic, and insulation were placed in appropriate bins. The steel hulks which remained were then loaded on a specially-designed dump truck and hauled to a local scrap-metal dealer.

Four people could usually recycle the day's refrigerators by noon, and the facility was then completely cleaned and ready for the next day's work by mid-afternoon. Great pains were taken both to safeguard the hazardous materials old refrigerators contain and to meet federal Occupational Safety and Health Administration (OSHA) standards for a healthy workplace. NYPA, OSHA, and the New York State Department of Environmental Conservation (NYS DEC) all conducted reviews of the facility and found it to meet or exceed relevant environmental requirements.

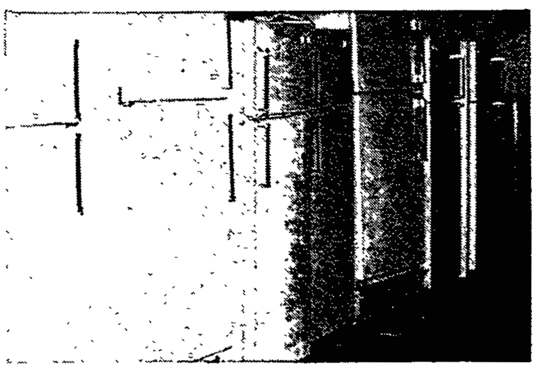

Photo 2-6. Refrigerators on the disassembly line.

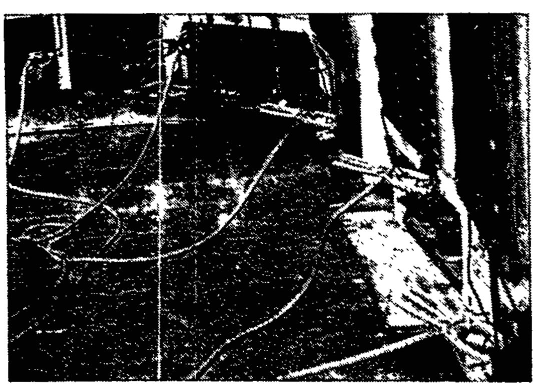

Photo 2-7. Refrigerant being removed.

Photo 2-8. Dennis Flack, Planergy's man in New York, designed the oil-draining rig shown below.

Photo 2-9. Oil draining rig

Table 2-2 gives a summary of the material recycled during the first year of the NYPA/NYCHA refrigerator replacement program.

Table 2-2. Recycled Material from Recycling 15,939 Refrigerators (Pounds)

Totals	Aluminum	Copper	Wire	Steel	CFC-12
Average per Refrigerator	5.31	0.36	0.36	170	0.29
Total (15,939 Units)	84,656	5,772	5,817	2,710,400	4,592

Data Collection

Synertech used two instruments for collecting energy use data on refrigerators during this project. The W-120 is a basic system consisting of a digital energy meter that measures true watt-hours to the nearest watt-hour and can be reset to zero by the user via the swipe of a magnet. The R-100 is an 11-channel dedicated refrigerator data logger. It measures and records in time series data records true watts, true watt-hours, defroster run time, door opening events and durations, and refrigerator, freezer, and ambient temperatures. Both instruments were developed by Synertech under contract to NYSERDA. The third appendix of the Project Plan, reproduced as Appendix B, is the reprint of a paper which reports on the development of both systems and discusses procedures for their use (Kinney and Stiles 1994).

Data Collection Protocol

Field work needs to be efficient and effective. It is important to observe and record relevant facts about a refrigerator, its location and use, and to be able to put the facts gathered to useful ends. The information needs to be recorded in a way that is accessible and easily displayed to be useful in per-unit decision making, day-to-day project management, and overall evaluation.

The field protocol used in this project was developed to achieve these ends. The data form and example data on one unit are shown in Figures 2-2a and b. A sample is reproduced on the form, illustrating the order in which information was gathered: client data, refrigerator information (from observation, including measurement with a tape) and energy consumption data.

Temperature measurements were typically taken by means of an infrared spot radiometer. These measure surface temperature, not air temperature, so they are not substantially affected by the rapid changes in air temperature within a freezer or refrigerator compartment which occur upon opening doors. A two-channel digital temperature sensor was also employed (or used as a back-up). A model that used low-mass thermocouples (having fast time constants) was best, since it had to come up to air temperature quickly. Very short door opening periods were important in taking temperatures with thermocouples, since these instruments sensed refrigerator air, which is replaced very quickly by room air when doors were opened. Note that run temperatures were measured at the beginning and the end of each test run: ambient, refrigerator, freezer, and behind the unit.

This last measurement is useful when refrigerators are tightly enclosed, thus impeding the flow of air that normally removes heat from the compressor and evaporator. High temperatures might suggest a strategy for lowering consumption by providing better circulation of air, either passively or actively.

The information on the first page of the audit form was entered onto an electronic data sheet, the screen version of which appeared identical to the paper form. When the user clicked on "Calculate," the software program developed for this project computed the information on the second page of the form and automatically stored all data in an Access™ database. A standard report was produced, which gave information on test runs as well as the four figures of merit at the bottom of the second page.

Refrigerator Audit Form - NYCHA

Synertech Systems Corporation

Audit Date: 3/1/96 | Site Location: Mott Haven | Sequence: 13D388

Customer Information

Customer: | Phone: | Occupants:

Address: 388 E 141 St apt 3D | City/St/Zip: Bronx

Refrigerator Information

Style: top freezer

\# doors: 2 | Defrost: Automatic

Mfr: Hotpoint

Model: CTH14CYXLRWH

Year Mfd: 1996 | Est?: No

	Height	Width	Depth	
Outside:	61.25	28.25	27	in.
Refrig:	37	25	22	in.
Freezer:	15	23.5	18.5	in.

Food Load: 70 % of Refrig

Food Load: 40 % of Freezer

Frost: 0 in., max accum.

Anti-sweat switch in position using electricity?: N/A

Refrig Control: 5 on scale of 9

Freezer Control: N/A on scale of

Consumption Data

Logger Model: W-120 | S/N: 015

	Start	Stop
Date and Time:	3/1/96 12:30:00 PM	3/8/96 10:57:00 AM
Logger Record No.:	0	0
Compressor On?:	Yes	No
Ambient Temp, deg F:	74	77.1
Behind Temp, deg F:	75	76.3
Refrig Temp, deg F:	40	49.3
Freezer Temp, deg F:	6	14.7

Measured Consumption: 14294 Wh

Est. Average Annual Temp: 0 deg F

Utility: NYPA

Rate: $0.08 per kWh

Notes:

Figure 2-2a. Data Form and Example Data

Calculate <<< Push this button to derived values which follow...

Parameter	Value	Units	Derivation
Mean temperature, ambient:	76	deg F	(ambient temp start + stop) / 2
" behind:	76	deg F	(behind temp start + stop) / 2
" refrigerator:	46	deg F	(refrig temp start + stop) / 2
" freezer:	10	deg F	(freezer temp start + stop) / 2
Volume, outside:	27.0	cu. ft.	outside height * width * depth
" refrig:	11.8	cu. ft.	refrig height * width * depth
" freezer:	3.8	cu. ft.	freezer height * width * depth
" interior volume:	15.6	cu. ft.	refrig volume + freezer volume
Adjusted interior volume:	17.9	cu. ft.	refrig volume + 1.63 * freezer volume
Elapsed Time:	166.5	hours	logger stop time - logger start time
Raw energy use per hour:	85.9	Wh	measured watt hours / elapsed time
per day:	2061	Wh	24 * raw energy use per hour
Net interior temperature:	36	deg F	(ref temp*vol) + (frz temp*vol) / (int vol)
Temperature difference:	-36	deg F	annual ambient - net interior temp
Correction factor:	0	%	2% * temperature difference
Adjusted energy use per hour:	85.9	Wh	raw use per hour * (1 + CorrFact/100)
per day:	2061	Wh	24 * adjusted use per hour
per year:	752	kWh	365 * adjusted use per day
Figure of Merit "T":	56.7	Wh/day/deg F	Adj. use per day / net interior temp
" "V":	115.0	Wh/day/cu.ft	Adj. use day / adj. volume
" "TV":	3.2	Wh/day/F/cu.ft	Adj. use day / net interior temp / adj. vol
Est. annual operating cost:	$60		Electric rate * Adj. energy use per year

Figure 2-2b. Data Form and Example Data (continued)

Data Logging Equipment and Procedures

The data-collection protocols for use with the R-100 11-channel refrigerator monitor are simplified by the fact that virtually all of the factors affecting performance are monitored by the logger's sensors. In practice, the data logger is plugged into the wall and the refrigerator is plugged into the data logger. This enables collection of data on voltage (volts), current (amperes), power (watts), energy (watt-hours), power factor (the ratio of real to apparent power, a unitless number), and defroster run time (seconds). Defroster run time is computed from software inputs during set-up, typically by thresholds of a power factor greater than 0.9 in combination with a current draw of more than three amps. (Compressors used in residential refrigerators typically draw less than two amps and have power factors of from 0.45 to 0.80 or so, unless they are equipped with power-factor-correction circuitry, as is the case with the SERP refrigerators and other new units produced by Whirlpool. Defroster heaters have a unity power factor and typically draw 3.3 amps or more.)

Three sensing devices are connected to the logger via telephone-style cable and J-38 connectors which plug into the back of the data logger. Each of the sensors installed in the refrigerator and freezer compartments houses a solid-state temperature sensor and a light sensor. Software in the R-100 enables setting the sensitivity of the light sensors so that door openings will be detected. The host software allows for gathering data at intervals from one minute to one hour; the routine for field testing is 15-minute intervals.

A time series data record is written to memory at the end of each collection period. This record includes the date and time of the period plus totalized information from the 11 channels of data over the past interval. The logger stores 16,000 data records before the on-board 512K memory is full, at which point new data begin to write over the oldest data.

The data are downloaded as an ASCII file to the host computer, typically a laptop in the field or a desktop in the office. They are analyzed via special-purpose software macros written into Excel™ or by related methods. Any of the data in this master database can be manipulated to produce graphic information in any number of forms via Excel™. In turn, this information can be imported into other software for making slides and overheads for presentation or into word processor software. Many slides were prepared in this fashion for presentation to members of the project advisory committee.

Over the course of the project, Synertech technicians used R-100 data loggers to perform one- to three-week-long tests on old and new refrigerators in the field. An R-100 data logger is shown in Photo 2-10, and the W-120 unit in Photo 2-11. Table 2-3 shows the number of R-100 and W-120 tests completed by old and new refrigerator and by site.

Photo 2-10. R-100 refrigerator data logger on a refrigerator in an apartment in the Edenwald development.

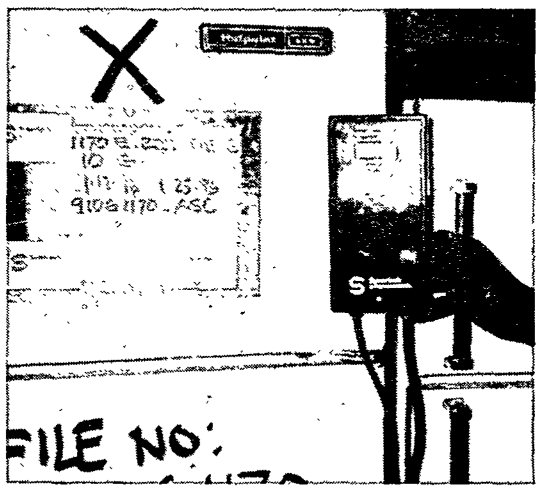

Photo 2-11. W-120 watt hour meter. The refrigerator shown has been measured in the field with an R-100 and is marked for delivery to Synertech rather than to Planergy's recycling center. After chamber testing, it will be recycled.

Table 2-3. Project Testing by Data Logger, Refrigerator Age, and NYCHA Complex

	Existing				**New**			**Totals**
R-100	**W-120**	**Total**		**R-100**	**W-120**	**Total**		
4	29	33		1	2	3		36
1	17	18		0	16	16		34
0	6	6		0	12	12		18
0	1	1		0	0	0		1
0	3	3		0	3	3		6
0	10	10		4	6	10		20
1	6	7		0	2	2		9
0	4	4		0	4	4		8
0	5	5		0	0	0		5
0	10	10		4	1	5		15
2	3	5		0	0	0		5
0	16	16		1	0	1		17
0	7	7		0	0	0		7
1	15	16		0	0	0		16
0	5	5		0	0	0		5
4	16	20		0	0	0		20
3	8	11		0	0	0		11
4	39	43		0	0	0		43
20	**200**	**220**		**10**	**46**	**56**		**276**

TRAINING

A day-long training session was held for technical staff of NYPA and NYCHA to promote understanding of both the philosophy and practice of accomplishing refrigerator testing in the field and conducting subsequent analyses. A training guide was developed which covered: principles of field evaluation; the rationale and analytical issues associated with short-term testing in general and testing of refrigerators in particular; testing protocols and analysis; and analytical hardware and tools. The guide is provided (without attachments) as Appendix C.

The day-long session included a two-hour session in the classroom (at NYPA) which focused on the principles of short-term analysis and hands-on demonstrations of equipment (the W-120, the R-100, and other electric energy-measuring devices and temperature sensors). Installations were then performed in an apartment complex close to NYPA's offices in mid-town Manhattan. Finally, a third two-hour session was held at NYPA to analyze findings, using both hand-held calculator and computer techniques. A copy of Synertech's database software was shared with NYPA personnel. The session included a discussion of special circumstances, hands-on work with the database software, and an evaluation of the day's training session.

ENVIRONMENTAL TEST CHAMBER

Synertech designed an environmental test chamber for testing refrigerators for this project and had it installed in its research/office facilities in downtown Syracuse, NY. Effectively a well-insulated commercial refrigerator with provisions for both heating and cooling, the unit was designed to test four refrigerators at a time. The chamber could keep ambient temperatures quite constant over a range of 50 to 100°F; standard deviations of less than 0.5°F over long test periods are routine. Chamber tests were run to determine how sample refrigerators performed under the DOE testing protocol, and how performance varied with changes in ambient temperature. The test chamber is shown in Photo 2-12.

Chamber testing of new units and commonly-found older units was helpful in evaluating the sensitivity of the units to changes in ambient temperature and to control setting, and in understanding responses to door openings, food loadings, and defrost cycling. (A door-opening mechanism is shown in Photo 2-13.) These parameters were useful both in producing accurate estimates of actual annual performance from short-term testing, and in providing pointed customer education. Chamber testing was also useful in investigating the nature of outliers from the field data. For example, several refrigerators were found to run the compressor and 400 watt defrost heater at the same time!

R-100s were used to measure refrigerator performance in the chamber and a dedicated personal computer was used to manipulate door openings via control signals transmitted through 120-volt lines. The software developed could set up door opening schedules to emulate the door openings as they actually occurred in the field, or accommodate a door opening "script" of the user's choice.

Photo 2-12. Test chamber at Synertech's research facility in Syracuse. Data downloads from the R-100s at the left are accomplished from an office 50 feet away.

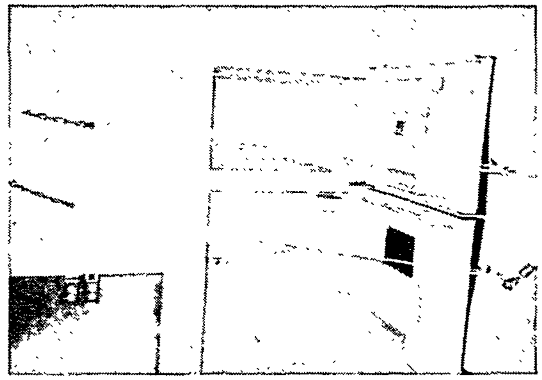

Photo 2-13. Door opening mechanisms were modified from hardware designed to control drapes.

Since Planergy's recycling facility is only a few miles from Synertech's research facility, selected units could be temporarily studied before being sent to their demise. Much was learned about both old and new units.

A key finding during chamber testing of the new GE refrigerator showed that a change in one degree F in the annual ambient temperature affects annual consumption of the unit by 2.5 percent. Table 2-4 shows the strong relationship between annual consumption of energy, control settings, and ambient temperature.

Table 2-4. GE refrigerator energy consumption (kWh/yr) vs. temperature and control setting (DOE-type test in Synertech's chamber--defrost period to defrost period--normalized to a 365.25-day year). The DOE test rating on this unit is 499 kWh/yr.

Chamber Temp	Control = 1	Control = 2	Control = 5	Control = 9
70°F	Not Tested	284	362	495

Section 3

DATA SOURCES

Calculation of the program cost savings involved the integration of several data sources:

- Records of the number of new refrigerators installed and model numbers for each existing refrigerator that was demanufactured;
- Total energy consumption monitoring in the field for a period of about one week for a sample of new and existing refrigerators, along with one-time measurements of ambient indoor air and fresh food and freezer compartment temperatures;
- Detailed 15-minute time-series metering of refrigerators in the field;
- Tests of the new refrigerator in an environmental chamber over a range of operating temperatures;
- A database of refrigerator characteristics including model numbers, DOE-label rating test results, rated volumes, defrost features, and year of production, as reported by refrigerator manufacturers;
- Daily outdoor temperatures (during field testing) and long-term-average monthly outdoor temperatures for New York City from National Weather Service data posted on the Internet; and
- Time-of-use electrical load shapes for ten NYCHA housing developments and the energy and demand rates charged by NYPA.

Each of the types of data used is described in this section.

REFRIGERATORS REPLACED

The number of refrigerators replaced is based on NYPA's records of the number of new refrigerators installed, and the models (and hence labels and sizes) replaced are based on Planergy's records of the model number of each existing refrigerator demanufactured. NYPA records show 20,000 GE refrigerators were delivered to NYCHA housing developments in 1996. Planergy shows 15,939 refrigerators were demanufactured. The difference in the number of models is explained by two effects.

1. Some residents refused to accept a new refrigerator, in many cases because they owned their own. In other cases, apartments were in the process of being renovated or remodeled to comply with access requirements for the handicapped. In these cases, a new refrigerator was placed in storage at the housing development until it could be installed at a later date.

2. Housing developments whose refrigerators were not scheduled for replacement until future years were salvaging some of the existing units in better condition to replace some of their oldest refrigerators. These very old units being replaced at these other developments usually did not make their way into Planergy's demanufacturing system to be counted. Of course, if the refrigerators were not demanufactured, no model number and hence no label rating can be determined. It is reasonable to assume that these refrigerators are represented by the average of those that were demanufactured. It is strongly recommended that, in the future, these housing developments bring old refrigerators to be recycled in equal number to those being salvaged (NYPA intends to enforce this in 1997). 1% of the units were also intentionally placed in basements as spares.[1]

The rate at which refrigerators are being installed in apartments is shown in Figure 3-1. Of the 20,000 refrigerators delivered in 1996 to NYCHA housing developments, the total number installed in apartments by NYPA is approximately 16,000. Figure 3-1 shows the rate at which the approximately 4,000 refrigerators placed in housing development basements are subsequently being moved into the apartments by NYCHA. Records show that over 1,000 were installed in December alone (indicated by the dark line), more than 25% of the remainder. At this rate, they will essentially all be installed by about April 1, 1997.

[1] It can be argued that if this were not done, then 1% of the existing units would have been retained as spares. If these were subsequently used to replace old refrigerators, savings would result. If these are used to replace new GE refrigerators that fail prematurely, then the failed units will not provide the expected cost savings. It is too early to tell whether 1% (200) of the new units can be expected to fail or be damaged by occupants remains to be seen. Whether savings for these 200 new refrigerators should be included is not considered in this report, but represents only a very small portion of the savings in any event.

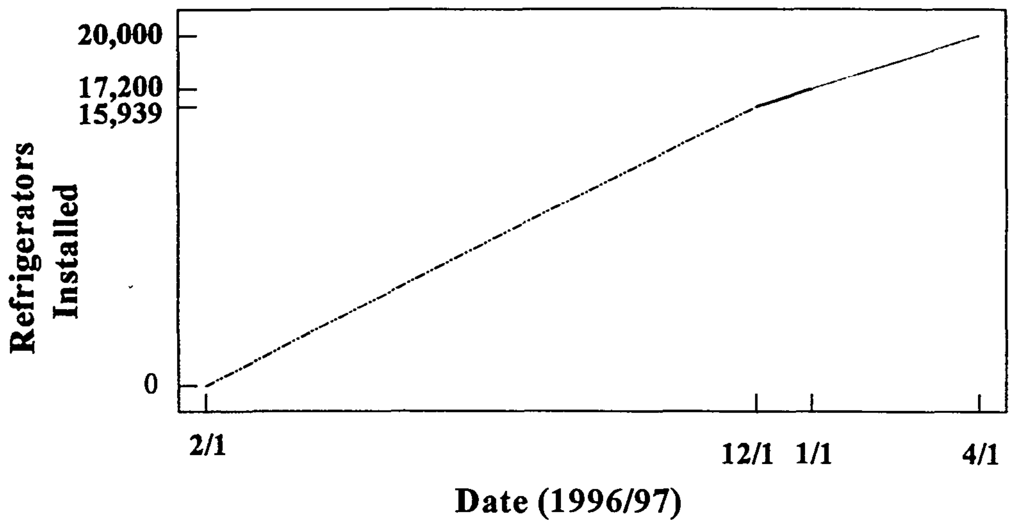

Figure 3-1. Rate of Refrigerator Installation in NYCHA Apartments

REFRIGERATOR LABEL RATINGS AND CHARACTERISTICS DATA

A database of refrigerator characteristics was used to look up DOE-label ratings for units replaced by the program. For many years, manufacturers have been required to provide DOE the results of energy consumption tests conducted in an environmental chamber for use as consumer label ratings. The label rating test is based on placing the refrigerator in a chamber maintained at an elevated temperature (90°F) compared to normal conditions to simulate door openings. After repeating the test at two control settings and measuring the resulting consumption and freezer temperatures, the results are interpolated to estimate annual consumption at a freezer temperature of 5°F. After testing several units off the production line, the average of their annualized consumption is issued as the label rating for a given model. DOE sets standards for maximum label ratings as a function of refrigerator volume. For each brand and model, this database contains the DOE-label rating, the rated volume, the year of production, and its defrost features.

All possible model numbers do not appear in this database. Manufacturers use parts of model numbers to specify things like color, which side the door is hinged, place of production, and other sub-model information. There also was a lapse in federally-mandated reporting of label ratings, and labels were not required at all prior to 1975. Some manufacturers produce refrigerators that are essentially identical but are sold under a variety of brand names and that have different model numbers. These appear separately in the database.

FIELD DATA COLLECTION AND CHAMBER TESTS

The field monitoring activities conducted by Synertech primarily involved short-term metering of total energy consumption over a period of approximately one week for a sample of existing refrigerators (n=256) and the GE high-efficiency replacement refrigerators (n=74). For each metered refrigerator, they also collected a variety of characteristics information, including refrigerator model numbers and dimensions. Synertech also collected snapshot data (at the beginning and end of the metering period) of key drivers for refrigerator consumption, including: indoor and refrigerator compartment temperatures using an infrared thermometer (radiometer), temperature control settings, and visually-estimated food loadings in each compartment.

In addition, Synertech complemented the energy consumption data with a small sample of refrigerators metered with data loggers (n=30) to collect much more detailed 15-minute interval data. In addition to power consumption, this included ambient air temperatures, fresh-food and freezer compartment temperatures, defrost cycles, and door openings and durations. This data was collected as a basis for understanding these key effects as well as peak load impacts. Weekly totals were also created from this data to add to the energy consumption sample.

No formal sampling scheme was established; residents were recruited for metering on an informal basis. Probably the most important consequence of this is that no metering was conducted for a period of about one month. During this time, the housing development at which installations were occurring was dominated by a particular model of refrigerator that was not sampled in other developments. So, although this model of refrigerator was the fourth most common model replaced, it was not included in the metered sample. Practical aspects of recruiting occupants and metering their refrigerators in New York City public housing also made it very difficult to meter a randomly selected sample of apartments. Occupants willing to allow access tended to be home when recruited, and cooperative with the housing authority and the metering personnel. So, some self-selection bias is undoubtedly present in the sample. Although the sample is not random in a formal statistical sense, it is felt that it is a reasonably representative sample of the occupants' refrigerator usage was achieved. Metering will be more uniformly distributed in time during 1997, and an attempt to randomize the recruitment process will be made.

After screening for data quality problems, some metered records had to be eliminated because:

1) The metering period was less than 48 hours;

2) Critical data used in the analysis were missing (usually the snapshot temperatures or the compartment dimensions);

3) The 15-minute time-series data was clearly incorrect for part of the metering period; or

4) A few new refrigerators were metered at control settings other than 2 or 5. Only those at these settings were utilized in the analysis (see below, Section 5).

Data were not eliminated for any other reasons, including very high or very low outliers as discussed below, to avoid biasing the results. After these screens were applied, a sample of 188 existing and 74 new refrigerators (including 17 metered at 15-minute intervals) was used in the analysis.

Consumption levels measured for several refrigerators were noted as outliers but not eliminated. Most of these were for existing refrigerators that had presumably malfunctioned. In at least once case, with measured consumption of over 5000 kWh/year, Synertech tested the refrigerator in its environmental chamber and confirmed that the unit was malfunctioning and indeed was consuming that much energy. There were also a few new refrigerators with very low consumption, less than their DOE-label rating by more than 1/3. These are harder to explain, but cool ambient indoor air temperatures, a low temperature control setting, and few door openings can produce such low consumption levels.

It should be noted that we examined the effect of these outliers on the results by repeating the analysis with and without them. To avoid biasing the results by manually filtering data, we defined outliers based on their label ratio (the ratio of their metered consumption to their DOE-label rating). Outliers were indicated when their label ratio was outside some number of standard deviations from the mean label ratio. When outliers were identified and removed on this basis, the savings estimates changed very little.[2]

Also, Synertech technicians noted early in the metering effort that the infrared radiometer used to make the snapshot temperature measurements produced consistently warmer readings than a thermocouple, particularly at the low temperatures in the freezer compartment. A correction factor was produced based on these dual measurements, as discussed in Appendix D. Unfortunately, however, the manner in which the measurements were taken changed over the course of the metering, so this correction factor could not be applied with any confidence and the temperature readings were left uncorrected. They should still be indicative of the *relative* compartment temperatures, but their absolute value is somewhat suspect. Accordingly, their ability to explain the variation in consumption from one household to another is limited.

Synertech constructed its own environmental chamber and conducted a series of tests to verify that the new refrigerators achieved their rated performance under the conditions of the DOE label rating test. These tests were then repeated over a range of chamber temperatures and compartment control settings to ascertain the effect of ambient and compartment temperatures on its efficiency. A supplementary test involving cooling a known volume of water was also conducted to estimate the COP (coefficient of performance, analogous to efficiency) of the compression cycle.

DEMAND AND CONTROL SETTING COMPLIANCE DATA

NYPA provided 15-minute total building electric demand records for ten NYCHA buildings in July and January. These are the metered power consumption levels at 15-minute intervals. These data were used to determine the time of day of building peak demands. NYPA also conducted a compliance survey to determine how many refrigerator controls were at various settings. This was done to determine the effect of a campaign to lower the settings because the temperatures in the new units proved colder than necessary.

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[2] The savings were slightly lower because several of the high-consumption outliers consumed as much as several times their label rating, probably due to malfunctions, while the low-consumption outliers were only about 50% of their label rating. So, elimination of the high outliers had more impact than elimination of the low outliers, lowering the mean consumption of existing refrigerators and, hence, decreasing savings.

Section 4

ANALYSIS PROCEDURE

The analysis activities were directed toward achieving a single objective: estimating the annual cost savings to NYCHA (at current NYPA electric rates) achieved by replacing existing refrigerators with the new GE model during calendar year 1996. Achieving a more generalizable understanding of savings as a function of refrigerator label ratings, occupant effects, indoor and compartment temperatures, and characteristics (such as size, defrost features, and vintage) is the subject of data collection and analysis efforts for 1997. Therefore, except for the peak load impacts, the measured data utilized were primarily the weekly energy consumption and snapshot data.

The analysis must account for four effects not directly represented in the raw data:

- Refrigerator consumption is largely proportional to the temperature difference between the compartments and the ambient indoor air, and indoor temperatures during week-long metering periods do not represent annual average conditions.

- Part way through the metering period it was discovered that the new refrigerators were operating several degrees colder than the existing refrigerators, and the manufacturers' default control setting was changed to compensate for this.

- Many more models of existing refrigerators were replaced than could be metered with any meaningful sample, and the efficiency of the existing refrigerators, as evidenced by their DOE-label ratings, varies widely (by more than a factor of two).

- The refrigerators' share of the building's peak load (upon which electricity demand charges are based) is less than their share of the average building energy consumption, because consumption by other appliances increases more during peak periods than does refrigerator's. So, cost savings for peak demand reduction must be accounted separately, instead of computed based on a blended-rate (the total electric bill for energy and demand charges divided by the number of kWh).

The analysis consists of five basic processes:

1. Adjust the measured consumption of each of the refrigerators from the indoor and compartment temperatures during the metering period to that which would occur under annual average conditions for the public housing population as a whole.

2. Construct a relationship between refrigerator consumption and DOE-label rating so that consumption can be estimated for refrigerator models not represented in the metered sample.

3. Use this relationship to estimate savings for each refrigerator replaced, and estimate savings attributable to changing the new refrigerators' control settings.

4. Estimate the consumption of refrigerators during the hours of peak building demand, and use it to compute the peak demand cost savings.

5. Use the records of the number of refrigerators of each model demanufactured to compute an average total per-unit savings for the program in 1996.

The key steps in the processes are summarized in the section that follows and several appendices of details. In the subsequent sections, two issues not addressed in the savings estimation procedure are discussed: performance degradation over time and heating/cooling interactions.

ANALYSIS OVERVIEW

Step 1. Adjust Metered Consumption for Annual Average Consumption

- Develop a relationship between indoor and outdoor temperatures for public housing in New York City based on the snapshot temperature data and the daily outdoor temperatures records. Then use long-term average monthly temperature data to estimate an annual average indoor temperature for the typical housing unit.

- Compute a weighted compartment temperature for each metered refrigerator by computing a surface-area-weighted average of the observed fresh-food and freezer temperatures. Assume it remains essentially constant throughout the year.

- Compute the average of the weighted compartment temperatures for all the metered refrigerators and assume this temperature is typical of all refrigerators in New York public housing.

- Estimate the annualized consumption of each metered refrigerator as if were operated in the conditions of the average housing unit. Two methods were used to do this. In the first (linear) method, each refrigerator's metered consumption is multiplied by the ratio of 1) the temperature differences (between the indoor and weighted compartment temperatures) for the annual average conditions in New York, to 2) the conditions measured at the beginning and end of the metering period. In the second (non-linear) method, we used a curve of refrigerator load as a function of the indoor and weighted-average compartment temperature difference, based on Synertech's chamber tests of the new GE refrigerator. These methods are described in more detail in Appendix E.

Step 2. Develop a Relationship Between Consumption and DOE-Label Rating

- This relationship is needed so that consumption can be estimated for refrigerator models not represented in the metered sample.

- Divide the annualized consumption estimate for each metered refrigerator by the label rating for that model to form a consumption/label ratio.

- Demonstrate that no statistically significant differences in the *ratios* are found between various models of refrigerators with sample sizes greater than 10. That is, if labels are taken into account, no difference between the performance of various models of existing refrigerator can be demonstrated.

- Construct a relationship between the refrigerator consumption in New York public housing based on a linear regression estimate of annualized consumption as a function of label rating. Use it to estimate the average annual consumption of each model of existing refrigerator replaced.

Step 3. Estimate Energy Savings

- Using this relationship, compute the per-unit energy savings for each model replaced (including those not represented at all in the metered sample). Do this on the based on the difference in the average annual consumption estimate for the model and the average of the annualized consumption for the new refrigerators set at the program's temperature control setting.

- Use NYPA's survey of refrigerator temperature control settings, before and after the campaign to change them to a setting lower than the manufacturer's recommendation, to determine how many occupants left the control setting unadjusted. Compute the fraction of the refrigerators that would be at the manufacturer's recommended setting (5) and those at the program's control setting (2) in order to match the average control settings surveyed for these time periods.

- Estimate the savings attributable to adjusting the new refrigerators' control setting based on these fractions and the difference between annualized consumption for refrigerators at the manufacturer's recommended setting (5) and those at the metered program's control setting (2).

- Multiply the savings attributed to the control setting adjustment by the fraction of refrigerators found in a post-installation survey to have been returned to the manufacturer's setting. Then subtract this from the gross per-unit energy savings to obtain the net per-unit energy savings.

Step 4. Estimate Peak Demand Savings

- Analyze time-of-use data for typical NYCHA buildings to determine the hours of day when peak loads occur. The approach used for this is discussed in Appendix F.

- Analyze the metered 15-minute refrigerator time-of-use data to determine the average load factor at the time of the building peak, i.e. the ratio of consumption during peak hours to the average hourly consumption for the year. Do this for both summer and winter seasons. The details of this are also discussed in Appendix F.

- Compute the peak load savings for each model of existing refrigerator as the product of the average load factor, the savings estimate for each model, and the demand rate charge.

Step 5. Estimate Total Per-Unit Savings

- Compute the total per-unit savings for each model of existing refrigerator replaced as the sum of the energy savings times the kWh rate paid by NYCHA, plus twelve monthly peak-load savings times the peak demand charge paid by NYCHA.

- Compute total program savings on a per unit basis by adding up the total per-unit savings for all refrigerators replaced and demanufactured for which label ratings could be found, dividing by the total number of these refrigerators. This implicitly assumes that, when either a model number was unknown or a label rating could not be found for an existing refrigerator, its consumption was equal to the average of all those replaced whose labels were found.

- Compute the confidence interval around the savings estimate from the variance explained by the relationship of consumption to DOE-label rating. The method used to compute the confidence interval is discussed in Appendix G.

PERSISTENCE OF SAVINGS

The persistence of savings for the program must be accounted in overall savings estimates. However, at this point there is little to indicate what these effects will be. Other studies have noted degradation of refrigerator performance over time. It seems reasonable to assume that the absolute rate of degradation is the same for the existing and replacement refrigerators. Then the difference between the consumption of the replacement refrigerators and the existing refrigerators replaced will remain constant over time, as shown in Figure 4-1.

This assumption of constant *absolute* rates of degradation corresponds to degradation modes not affected by the relative efficiency of the refrigerators, such as door seal leakage in refrigerators with similar compressor efficiency. Loss of insulation quality, compressor efficiency, or heat exchange effectiveness may be better reflected in similar *relative* degradation rates, that is, by a similar *percentage* degradation per year for both classes of refrigerator. Since the replacement refrigerators are efficient, their *absolute* degradation rate would then be smaller in this case, and the slope of the degradation line for the replacement refrigerators would be lower than for the existing refrigerators.

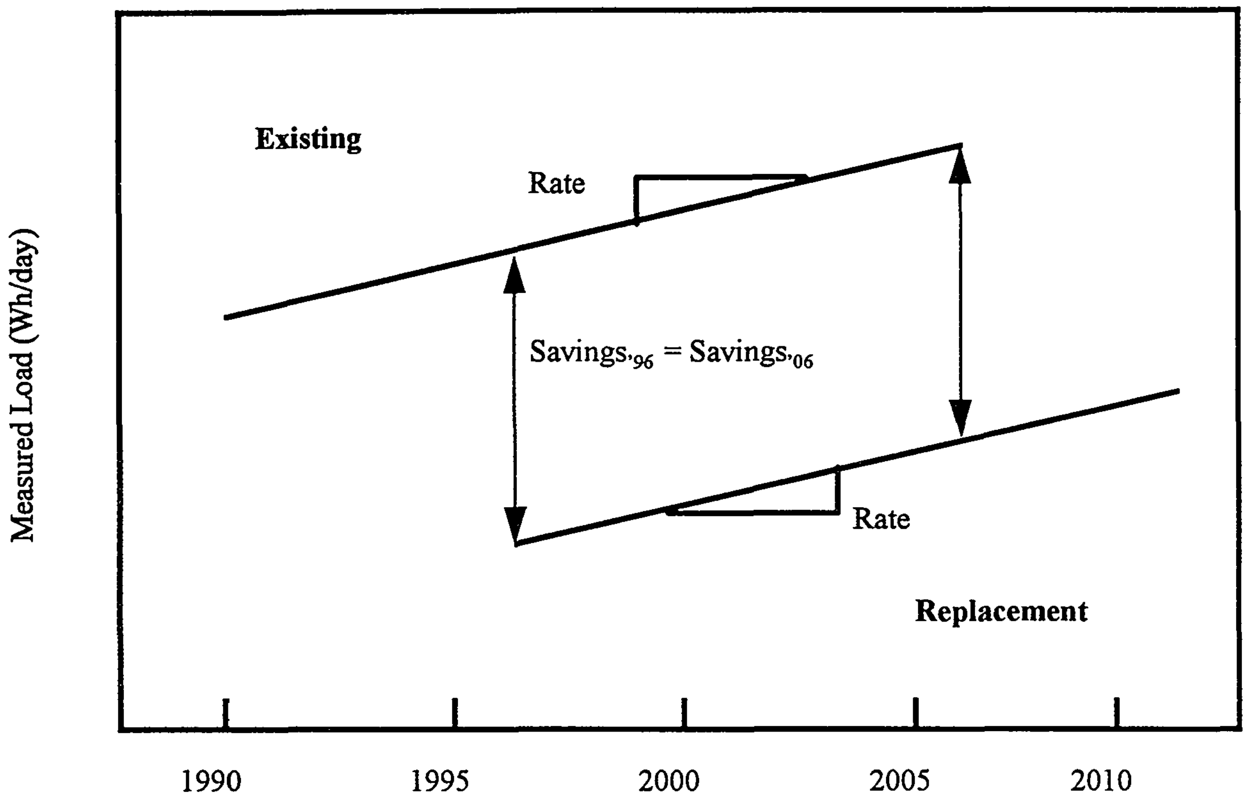

Figure 4-1. Effect of Refrigerator Performance Over Time on Savings (Assuming Equal Absolute Degradation Rates)

The program has two means of gathering further information in this area. First and foremost, this is a subject for study using spot metering of 1996 refrigerators in forthcoming years. Second, some attempt could be made to compare the label ratings of the old refrigerators with their performance in the chamber tests. This would provide an estimate of the actual degradation rate of the existing sample, but obviously would not help with the new sample. However, these efforts were left for future years.

HEATING/COOLING INTERACTIONS

We assume that there are not substantial heating and cooling interactions due to the reduced level of heat given off by operation of the replacement refrigerators. These interactions are in the form of increased winter heating loads and decreased summer cooling loads. This is because housing unit temperatures are generally not controlled by individual thermostats, but rather are set for the building as a whole. It is unlikely that these settings will be reduced from current levels as a result of this program. Most apartments are not air conditioned, so cooling interactions will be small. Given the uncertainty in quantifying this effect, the additional expense for data collection and analysis was not worthwhile for this class of multi-family building.

Section 5

RESULTS

The results of the analysis are summarized in this section.

COMPARISON OF NEW AND EXISTING REFRIGERATOR CHARACTERISTICS

A comparison of the characteristics of the new and average existing refrigerators is presented Table 5-1. Recall that NYPA records show 20,000 refrigerators were replaced in 1996 with the GE model, while Planergy shows 15,939 refrigerators were. As evidenced by their much lower label rating (499 kWh/yr), the new refrigerators are much more efficient than the average refrigerator replaced by the program.

Table 5-1. Characteristics of the New and Existing Refrigerator Populations

Characteristic	Existing	New	Difference
Refrigerator Count	15,939	20,000	-4,061
Internal Volume (population weighted), ft^3	12.6	14.4	-1.8
DOE Label Rating (population weighted), kWh/yr	911	499	412

The new refrigerators are significantly larger than the average unit replaced (14.4 ft^3 compared to 12.6 ft^3). This provides considerable qualitative benefits to the residents. Since refrigerator heat loss and hence energy consumption are directly proportional to surface area, savings would be even higher if the new refrigerators were the same size as the existing units. A simple estimate of the extra energy savings that would have occurred had the new refrigerators been as small as those replaced (based on the ratio of the volumes) is 72 kWh/yr.

Another similar qualitative amenity the new refrigerators provide is automatic defrost. Most of the existing units are manual defrost models. A simple comparison of the difference in historical DOE-label ratings for refrigerators of this size provides an estimate of the energy consumed by the defrost cycle: around 140 kWh per year.

Indoor Air Temperatures

The indoor air temperature in NYCHA apartments goes through strong seasonal variations. The indoor temperatures for each metered refrigerator are plotted as a function of the daily average outside air temperature for the period metered in Figure 5-1. Note that these indoor temperatures are not literally daily averages, but instead are the average of snapshot measurements taken at the beginning and the end of the metering period. The daily-average outside temperatures are determined from National Climatic Data Center weather data for the corresponding period.

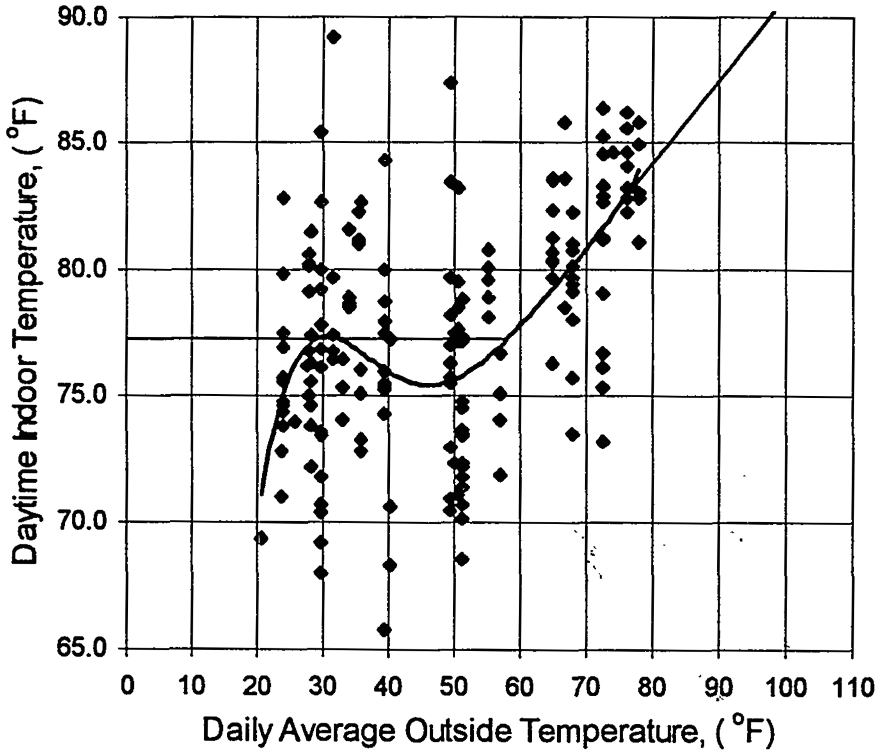

Figure 5-1. Relationship of Indoor and Outdoor Air Temperatures in NYCHA Housing

The apartments are very warm on average, even in winter. This is because the units do not have heating thermostats, and the superintendents are required to meet temperature requirements in the coldest units. The average indoor air temperature was about 77°F during winter months; summer temperatures rose to an average of 83°F in July. Note that the warm indoor temperatures actually increase savings, because, although consumption of both the new and replacement units increase, the existing units increase faster because they are not insulated as well.

The curved line represents a polynomial fit to the data. It indicates a general upward trend above about 55°F. Despite the considerable scatter in the data, we interpret this to be representative of indoor temperatures that are controlled in the winter through heating, yet continue to rise in the summer due to the lack of air conditioning. We represent this by a constant indoor temperature when it is colder than 58°F outside and a steadily increasing indoor temperature when it is warmer outside. This is shown by the straight lines superimposed on the plot. We use this segmented linear model to estimate the indoor air temperature of the average NYCHA housing unit at any outdoor air temperature.

The segmented-linear model is used to determine an annual average indoor temperature. Average monthly temperatures (over 30 years) are used as inputs. The resulting predicted monthly indoor temperature is shown in Figure 5-2. A simple average of these 12 predicted temperatures is used to represent the annual average indoor temperature for NYCHA apartments, 78.7°F.

REFRIGERATOR CONTROL SETTINGS AND TEMPERATURES

The average of the weighted compartment temperatures (a surface-area weighted average of the fresh-food and freezer compartment temperatures) in the existing sample was 39.3°F. The new units ran several degrees cooler when operated at the manufacturer's factory control setting of 5. The average weighted compartment temperature was 1.2°F cooler, and the freezer compartments were 2.5°F cooler. It is hypothesized that this may be due to a poor setting for the splitter damper that allocates cold air to the two compartments when the compressor is on.

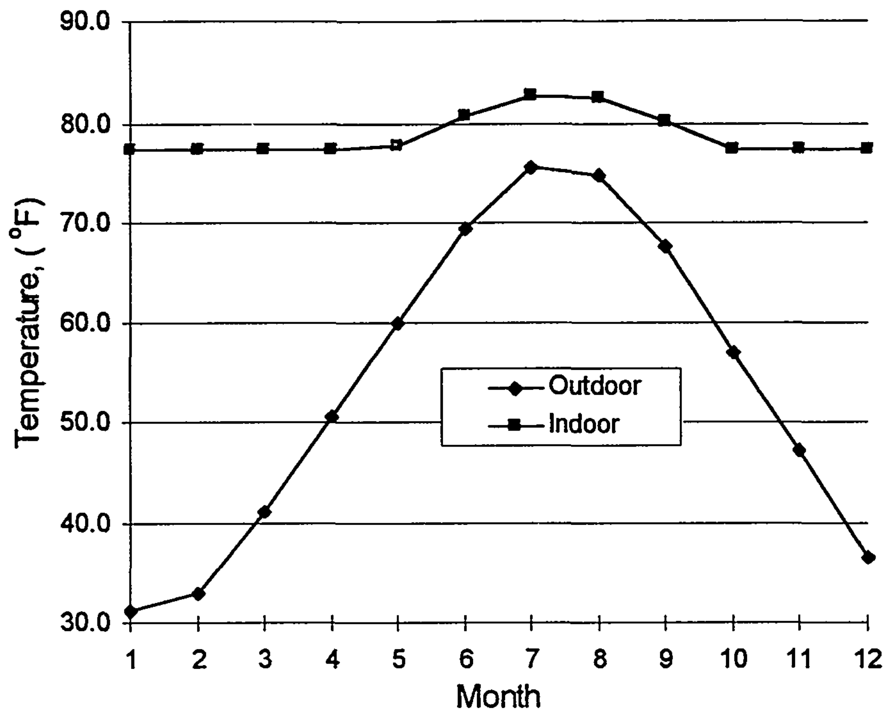

Figure 5-2. Average Monthly Indoor Air Temperature for NYCHA Apartments

Consequently, NYPA began changing controls to a setting of 2 at the time of installation, and NYCHA began an education campaign to keep them there (and change those already installed). NYPA subsequently performed a survey for compliance with the adjusted control settings. The purpose of this survey was to determine how many residents changed their control settings after installation.

The results of this survey are summarized in Table 5-2. Prior to the adjustment campaign the average control setting was 4.56; after the campaign the setting averaged 3.06. The table shows that most occupants (74%, or 25 of 34) did not change their control setting from 2 after the campaign began. Of those that did change their setting, 18% changed it to 7 (6 of 34), 3% each changed it to 5, 4, and 3 (1 of 34).

Table 5-2. Control Setting Adjustment Compliance Survey Results

Housing Development	No. Refrigs. Found at a Control Setting						Avg. Control Setting	Equiv. % Set At	
	2	3	4	5	7	All		2	5
Fulton	2	1	0	4	2	9	4.56	15%	85%
Subtotal, before campaign	2	1	0	4	2	9	4.56	15%	85%
Bronxdale	13	0	0	4	2	19	3.16	61%	39%
Subtotal, during campaign	13	0	0	4	2	19	3.16	61%	39%
Adams	9	1	0	1	5	16	3.81	40%	60%
Ravenswood	16	0	1	0	1	18	2.39	87%	13%
Subtotal, after campaign	25	1	1	1	6	34	3.06	65%	35%

It is notable that the majority of the changes to the control settings occurred in the Adams development, with much different results in Ravenswood. A larger survey might reveal the changes at Adams to be atypical, resulting in increased savings.

Because we have large samples of new refrigerators metered with their control settings at 2 and at 5, we compute the fraction of the population that would be at both 2 and 5 to produce equivalent average settings. This implicitly assumes a linear relationship between control setting and consumption. The average setting before the campaign is equivalent to 15% of the controls being at 2 (and the rest at 5), while afterwards this rose to 65%. This is shown in Table 5-2. For example, the calculation for the subtotal after the campaign is computed from

average control setting = (25*2 + 1*3 + 1*4 + 1*5 + 6*7) / 34 = 3.06 (n=34)

no. set at 5 (to produce average control setting) = (3.06 – 2) / (5 – 2) = 0.334

checking: 0.334*5 + 0.647*2 = 3.06

We will report savings at both a control setting of 2 and at the average control setting below in this section.

TEMPERATURE-ADJUSTED ENERGY CONSUMPTION

The metered consumption of each refrigerator was adjusted as if it were operated at the average annual indoor temperature, 78.7°F. As a check to ensure that the linear and non-linear methods (discussed in Section 4 and Appendix H) do not produce significantly different results, we used them both and compared the results. We also examined the effect of adjusting all the metered consumption data to a common weighted compartment temperature: the average of all the existing units. The results show that the savings estimates are not significantly affected by these methodological variations, as documented in Appendix H.

We used the results from the linear method because it does not depend on any assumption about similarity of the compression cycle COPs (coefficients of performance) in the new and existing units. Practical considerations suggested that we adjust consumption only for the average annual indoor air temperature. This is because adjusting to a population-average compartment temperature tends to remove the effect of changing the control settings from 5 to 2 in the new GE units, and this is a key result desired from the analysis. After these adjustments were made, we computed a label ratio by dividing the adjusted consumption of each refrigerator by its DOE-label rating.

We then compared the savings estimates that resulted from conducting a stratified analysis and a model-based analysis. In the stratified analysis, we separately analyzed each group, or stratum, of existing refrigerators that were determined to be identical for the purposes of this study. That is, based on their model numbers, they were found to be produced by a common manufacturer, had identical label ratings and defrost features, and were produced in the same or adjacent years. If so, they were grouped to define a stratum and their consumption was averaged. As a result of the stratification process, all the metered refrigerators were grouped into one of 29 strata or, if less than a minimum sample of a stratum was metered, it was arbitrarily assigned to a catch-all stratum.

Our minimum sample threshold to define a stratum as being metered was, liberally, set to two. This still leaves 37% of the replaced refrigerators without any metered sample. For these strata we assumed that their label ratio was the same as the population-weighted average label ratio of the existing refrigerators in metered strata.

In both approaches, if no DOE-label rating was available, we simply assumed the consumption of a refrigerator was equal to the population-weighted average consumption of the metered refrigerators (1206 kWh/yr).

The problem with the stratified analysis is that few strata had enough metered representatives to provide good consumption estimates. Only four of the 29 strata had a sample with more than 10 refrigerators, and 19 strata had samples with less than five. We found during the course of the year that savings estimates for the whole program could change by as much as 10% when just a few data points were added. This is because if a stratum has only a small sample, and an outlier is added to it, then the mean for the stratum changes substantially. If this stratum also represents a large number of replaced refrigerators, and so carries a lot of weight in the final result, the savings estimates could change significantly. The variance within strata was also noted to be very high. The standard error of the estimate of the average consumption level was over 100 kWh/year for 15 of the 28 strata, and over 150 kWh/yr for eight of the strata (see Table H-2 in Appendix H). This does not lend confidence in using strata means to represent large numbers of replaced refrigerators.

In the model-based analysis, all refrigerators are assumed to perform in the field about the same relative to their DOE-label rating. That is, the average label ratios of all strata are about the same. We demonstrate the validity of this assumption in Figure 5-3. This is a box plot[1] comparing the distribution of the label ratios in the five strata with the largest metered samples (n>9). Each box has a notch indicating the 90% confidence interval of the stratum. If the range of any of these notches overlap for any pair of strata, this is interpreted as indicating that the label ratios of the two strata do not differ in a statistically significant way. (The new refrigerators also form a "stratum" for this purpose.)

[1] In a box plot, the median of each stratum is shown as the "waist" of the notch in the middle of the box. The extent of the box above the median indicates the 3rd quartile of the data (from the 50th to the 75th percentiles), while the extent of the box below the median indicates the 2nd quartile (25th to 50th percentiles). The ranges of the upper and lower quartiles are shown by the extent of the lines extending up and down from the boxes. If the notch exceeds the extent of the quartiles, they can still be seen by looking for the lines extending from sides of the notch that indicate their extent. Outliers, defined as data points outside 2.5 standard deviations from the mean, are not shown.

It can be seen that only the first stratum is different, and it is only different from the last two strata. The confidence intervals of the other four strata overlap, indicating they are statistically similar. On this basis, we judge that there are not statistically demonstrable differences in performance of one model of refrigerator compared to another that are not explainable by differences in their DOE-label ratings.

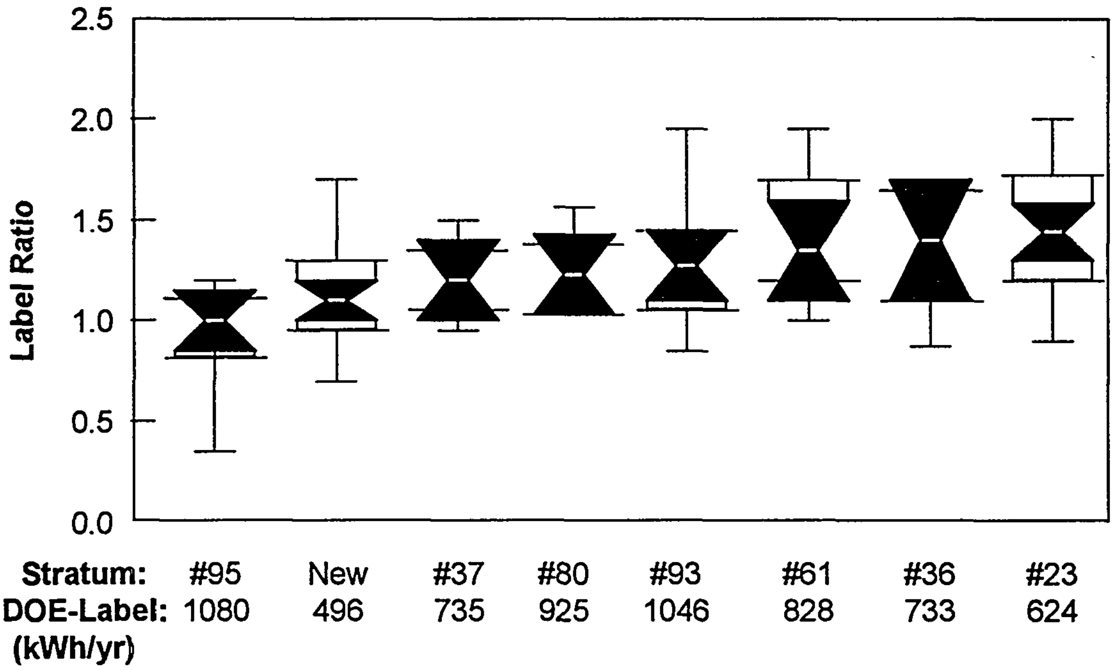

Figure 5-3. Distribution of Label Ratios for Strata with Large Samples

We then constructed a regression-based relationship between metered consumption and label rating using all the metered refrigerators. This relationship is illustrated in Figure 5-4. The model only explains a fraction of the variance (R^2 of 0.18, or 18%) due to the high scatter in the data already noted. However, the t-statistic on the slope is 6.1, indicating that it is statistically quite significant. We tried adding several other variables to this model to improve it, including control settings as a fraction of the dial range, food loading levels, defrost features, year produced, and rated volume. None provided any statistical benefit. We attribute the unexplained variance to wide ranges in occupant behavior with respect to the number and duration of door openings and food loadings. Variations in refrigerator condition and indoor humidity levels can also have strong effects on energy consumption.

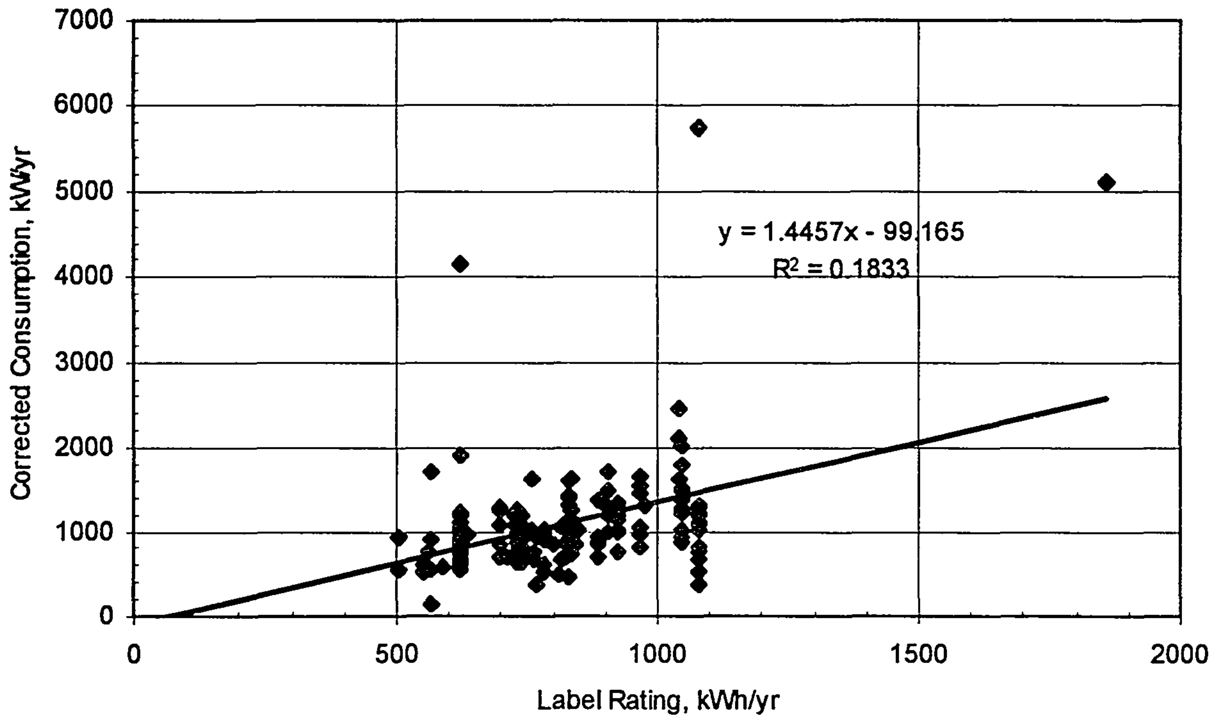

Figure 5-4. Relationship of Consumption to Label Rating for Existing Refrigerators

Other field metering studies have found label ratios of about 0.9, whereas in this study the new and existing units are at 1.3. These other studies are of single-family dwellings, which are much cooler during the course of the year, on average. The difference in temperature explains about 75% of the difference. Other factors may include the small size of the old refrigerators, the high efficiency of the new units, and some degradation in the existing units. This is discussed at greater length in Appendix I.

DEMAND SAVINGS

Data from ten NYCHA buildings with 15-minute load data metered by NYPA were examined. Their peak loads occur at an average of 9 p.m. in the summer and 7 p.m. in the winter. For the 17 refrigerators metered at 15-minute intervals for about one week, the average of their load shapes (hourly consumption divided by average consumption during the metering period) is shown in Figure 5-5. The raw data were noted to produce a very irregular load shape, unlike the smoother load shape that would be expected from the average of a larger sample (and/or a longer metering period). So, the data were smoothed using a rolling average over a 75-minute time window. We used this somewhat smoother load shape, also shown in Figure 5-5.

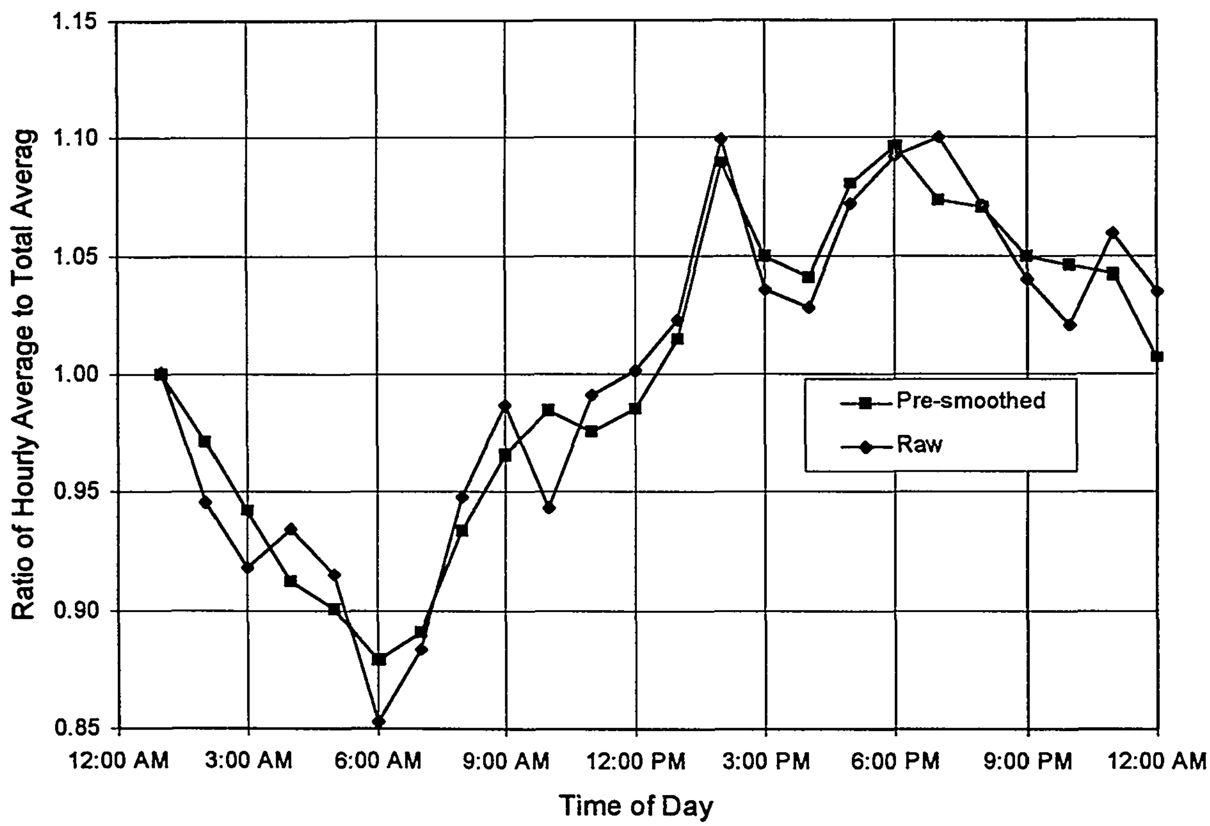

Figure 5-5. Average Daily Load Shape for 17 NYCHA Refrigerators

Only five refrigerators were metered in the winter season. Given the high degree of variability exhibited by the full sample of 17, we did not have confidence in differentiating winter and summer refrigerator load shapes with this data. Approximating the time of the building peak demand as an equal number of winter and summer months, the average annual load for these peak hours was 1.064 times higher than the average load. Given the short duration of the metering and the small sample size, the demand savings estimates are relatively uncertain (and could be higher). Metering in 1997 will all be on a 15-minute interval basis, so these estimates should become more precise in the future.

ELECTRICITY COST SAVINGS

The energy and cost savings for the refrigerator replacements in 1996 are summarized below are based on NYPA's electric rates for both energy (kWh) and monthly peak demand (kW), including distribution surcharges applied by Consolidated Edison. NYCHA considers its energy cost on the basis of an effective blended rate of $0.085/kWh. They compute this by dividing the total electric bill by the kWh consumed. This is a useful simplification, but it is not the basis upon which they are billed. The blended rate is only accurate for computing the value of savings from efficiency improvements in equipment or loads that have the same ratio of energy to peak demand that the total electric consumption of the housing development does.

For the refrigerators, a similar blended rate can be computed. Using the existing refrigerators as an example, the energy cost of a year's operation at 1207 kWh/yr is $42.69/yr. The average demand over the year is 0.138 kW (1207 kWh/yr divided by 8760 hours per year). As discussed previously, the 15-minute data show that, at times of building peak demand, the refrigerators loads are 1.064 times larger than average, or 0.146 kW. Because this is billed 12 months per year at $22.31/kW, the demand cost for the refrigerator is $39.25 per year. The total annual cost to operate the refrigerator is thus $81.91. Dividing this by the 1207 kWh consumed gives a blended rate for refrigerators of $0.068/kWh.

The blended rate for refrigerators is lower than the housing development's because the buildings' total load during peak hours was about 1.6 times the average, while the refrigerators were much closer to their average load (1.064). Performing a similar calculation, the energy the *whole building* consumes yields the building's blended rate

(1 kWh/yr * $0.0354/kWh +
1 kWh/yr / 8760 hr/yr * 12 month/yr * $22.31/kW-month * 1.6 ratio of peak to average)
/ 1 kWh = $0.084/kW

SAVINGS

Table 5-3 shows the average savings per refrigerator if all the new GE refrigerators had remained at a control setting of 2, as installed. Then the energy savings would have been the difference between the average consumption of the existing refrigerators (1207 kWh/yr) and the GE refrigerators operated at 2 (563 kWh/yr), or 644 kWh/yr. The savings that could be achieved if all residents comply with NYCHA's directive to keep the control settings at 2 are an average $43.71 per year per refrigerator (all costs and savings are reported in 1996 U.S. dollars).

Table 5-3. Savings if All New Refrigerators Were Set at 2

Refrigerator Group	Label kWh/yr	Label Ratio	Energy kWh/yr	Energy $/yr	Demand kW/mo.	Demand $/yr	Total $/yr
Existing	903	1.34	1207	$42.71	0.147	$39.24	$81.95
New, Set @ 2	499	1.13	563	$19.93	0.068	$18.31	$38.24
Savings, New All @ 2			644	$22.78	0.078	$20.93	$43.71

We assume that the new refrigerators will remain at an average control setting of 3.06, as indicated by NYPA's survey (Table 5-2). This is computed as the weighted average of 65% of the savings when the new refrigerators were set at a control setting of 2 and 35% of the savings when they were at a control setting of 5. As shown Table 5-, on this basis the savings for the average refrigerator replaced in the program is estimated as 578 kWh per year and the demand savings average 0.070 kW per month. This represents $20.46 per year in energy cost savings and $18.79 per year in demand cost savings, a total of $39.25 per year. The 90% confidence interval in the savings estimate was computed at ±10%, as documented in Appendix F.

Table 5-4. Population-Weighted Energy, Demand, and Cost Savings

Refrigerator Group	Label kWh/yr	Label Ratio	Energy kWh/yr	Energy $/yr	Demand kW/mo.	Demand $/yr	Total $/yr
Existing	903	1.34	1207	$42.71	0.147	$39.24	$81.95
New, Set @ 2	499	1.13	563	$19.93	0.068	$18.31	$38.24
New, Set @ 5	499	1.50	749	$26.51	0.091	$24.36	$50.87
New (65% Set @ 2, 35% Set @ 5)	499	1.26	629	$22.25	0.076	$20.44	$42.70
Savings, Total Program			578	$20.46	0.070	$18.79	$39.25

A larger control setting compliance survey might reveal the changed settings at the Adams development to be aberrant and that compliance is as good as in Ravenswood (see Table 5-2 and associated discussion). If so, then the savings estimate resulting from a weighted average of 87% at 2 and 13% at 5 would increase about 7% to 619 kWh/yr ($42.06/yr).

The effect of the campaign to adjust the control settings is illustrated in Table 5-5. This is estimated as the difference between the energy consumption of the existing refrigerators and the new refrigerators at the average control settings *before* the campaign (15% at 2 and 85% at 5, as shown from NYPA's compliance survey in Table 5-2). 93 kWh/yr (16%) of the 578 kWh/yr in energy savings is estimated to be the result of the adjustment campaign.

Table 5-5. Savings from Control Adjustment Campaign

Refrigerator Group	Label kWh/yr	Label Ratio	Energy kWh/yr	Energy $/yr	Demand kW/mo.	Demand $/yr	Total $/yr
Existing	903	1.34	1207	$42.71	0.147	$39.24	$81.95
New (15% Set @ 2, 85% Set @ 5)	499	1.45	721	$25.54	0.088	$23.46	$49.00
Savings Est., No Control Adjustment			485	$17.17	0.059	$15.78	$32.95
Savings, From Control Adjustment			93	$3.29	0.011	$3.02	$6.30
Savings, Total Program			578	$20.46	0.070	$18.79	$39.25

COST EFFECTIVENESS

NYPA's cost for purchase, installation, and recycling of the old refrigerators was $356 each for the first year of operation, excluding overhead. Accordingly, at an average saving of $39.25 per year, the simple payback for the first program year was 9.1 years. Assuming a 4.7 percent discount rate and a lifetime of 20 years, the savings-to-investment ratio (SIR) was 1.38. Accordingly, since the SIR is greater than one, the program was cost effective in its first year of operation.

Section 6

CONCLUSIONS AND RECOMMENDATIONS

At the end of the first year of the largest and most ambitious refrigerator replacement program in the history of public housing in America, it is clear that the program is a success. As documented in Sections 4 and 5, substantial savings in energy and power were achieved. Both are important. Because the price NYPA charges for energy (kWh) is quite low, a substantial portion of the cost effectiveness of the replacement program was due to demand savings (kW).

A number of other benefits also resulted from the program:

- The receipt of new refrigerators was welcomed by residents, many of whom expressed their delight. The new units came equipped with automatic defrosters, a feature missing from most of the refrigerators that were removed and recycled. Since the new units require less attention to maintain efficiency, it is likely that energy performance will be stable over a longer period. Further, in many cases residents received refrigerators larger than their old ones.

- The new refrigerators installed have power factor compensation circuitry so that the line "sees" a power factor of about 0.89 when the compressor is running. Although not measured on all units tested, the average power factor of the refrigerators removed is probably approximately 0.7. This is an advantage to NYPA since the closer power factors are to unity, the less power per true watt consumed must be supplied by the utility.

- The project demonstrated that recycling can be accomplished efficiently, cost-effectively, and in good coordination with the installation of new units. Recycling old units gets them off the grid permanently, provides feedstock for the scrap metal and refrigerant industries, keeps dangerous substances out of the environment, and has economic multiplier effects owing to salaries paid to people in the recycling and transportation operations.

- Manufacturers of energy-efficient refrigerators now realize there is a substantial and growing market for their product and an effective way to move newly-manufactured units from factory to end user with minimal cost and complexity. Marketplace transformation is a reality and momentum is building.

Project success to date is principally due to good planning, management, and coordination between all involved. This observation applies throughout the process--from the development of a vision for influencing the efficiency and cost of products bought in bulk through day-to-day production, record keeping, and dealing with crises, to analyzing results.

KEY FINDINGS FLOWING FROM FIELD AND CHAMBER MEASUREMENTS

The energy performance of refrigerators is a very strong function of the difference in temperature between the cooled compartments and the local environment. Control settings primarily determine the temperature of the fresh food and freezer compartments. A change in the difference in the interior-to-ambient temperature of 10°F can result in a change of 25 to 30 percent in annual energy use.

To a lesser but important degree, the interior temperature also depends on loading patterns (the temperature, thermal mass, and "accessible" moisture content of the food and drink put in the fresh food and freezer compartments). Inserting a warm mass in the freezer, for example, not only raises the temperature of the freezer but also lowers the temperature of the fresh food compartment for the period in which the compressor runs to cool the mass in the other compartment. This is because the damper between the two compartments is fixed. In consequence, lettuce in the fresh food compartment can freeze when a set of ice trays containing warm water is placed in the freezer. Similarly, warm food inserted in the fresh food compartment lowers the freezer temperature (by as much as 20°F). In both cases, energy is wasted.

Chamber testing showed the degree to which temperature differences (owing to control settings and ambient conditions) affect the performance of new and old refrigerators. With the new refrigerators, chamber testing revealed the importance of setting temperature controls at 2 (on a scale of 9) instead of 5 (the initial setting from the factory) in order to achieve performance consistent with the DOE standard (listed as 499 kWh/yr for the GE unit installed in the first year of the program). Testing also showed the range of temperatures which exist over compressor and defrost cycles, demonstrating that freezers with modest loads run at well above freezing for over half an hour following defrost heater runs. (The auto defrost feature adds almost 10 percent to the annual energy budget.) Chamber testing also signaled the need for a damper between the fresh food and freezer compartments that is responsive to food loading, a fact that is not revealed by traditional DOE test procedures. Finally, chamber testing strongly suggests that improvements in the performance of both the cooling system (which shows an effective COP of only 1.0 for the new GE unit) and the insulated envelope are quite technically feasible. All of this bodes well for the future of the development of still more energy-efficient refrigerators, particularly if manufacturers are responsive to market, bulk purchasing, regulatory, and other stimuli.

There is great diversity of refrigerators; the 1995 Association of Home Appliance Manufacturers (AHAM) directory of refrigerators by manufacturer lists over 40,000 distinct models that were produced by American manufacturers in the 30 years preceding its publication. We found over 500 models among the first 17,000 refrigerators removed from NYCHA apartments, and many of these were not listed in the AHAM directory. This diversity, coupled with the fact that inventories of existing refrigerators by apartment either do not exist or are inaccurate, made it difficult to select a sample for testing which accurately reflects the population. On the other hand, since the refrigerators are brought to a central location for recycling, a database can be developed that reflects accurately what has been removed. Accordingly, the analyst can quantify uncertainties with precision. Thus, if counts at the recycling facility show that frequently-occurring models were undersampled in field testing, this fact may be useful in directing further testing and accurately weighting the analysis.

Since inside-outside temperature differences have such a large effect on energy consumption, accurate estimates of refrigerator performance require knowledge of: (1) the slope of the annual energy performance versus ΔT curve for various commonly-found refrigerator models, (2) the average ambient temperature during field tests of energy use, and (3) availability of accurate data on annual ambient temperature in apartments. At present, we know something--but not enough--about each of these three factors.

During the first year of the program, only a small sample of existing refrigerators could be tested at different temperatures and control settings in the chamber. However, the spread was quite large (from 1 to 4.5 percent of energy consumed per °F ΔT) in the five units tested. More chamber tests of frequently-found models should be performed.

The R-100 data logger records temperature information continually, but only 20 field tests of existing refrigerators and ten of new refrigerators were run with the R-100. These 30 sets of data from tests, which ranged from one to three weeks in duration, were used for estimating average annual apartment temperatures of thousands of apartments in 19 building complexes. The 246 W-120 tests included only snapshots of temperature at the beginning and end of each test period.

RECOMMENDATIONS

The Coming Program Year

Maytag Testing. The decision has been made to purchase the new Maytag unit. Its DOE test rating is 12 percent better than the GE unit and its cost is somewhat less. The manufacturer claims that the middle range of control settings will yield the rated performance under DOE test conditions, so it seems likely that the Maytag unit will outperform the GE refrigerator by more than 12 percent in the field. Since this is a new design, we recommend thorough testing in the chamber and in the field. Chamber testing should be accomplished both to verify basic DOE test results and to produce a table of consumption versus ambient temperature and control settings. Drift tests and loading tests should also be accomplished to quantify the COP of the cooling system, to estimate the effective R-value of its envelope, and to assess how the temperatures of the fresh food and freezer compartments vary with loads. The resulting information will be useful both in evaluating the program savings and in developing information useful for conducting resident education.

Other Chamber Tests. To estimate overall project savings more accurately, chamber tests of selected refrigerators removed from apartments should be run to determine consumption versus ambient temperature curves of all units of which there are at least 200 exemplars.

Field Testing and Instrumentation. Field tests of both old and new units should continue at about the same levels as year one (one percent for existing, 0.5 percent for new). It would be helpful to have a simple, efficient data logger capable of collecting spot data on voltage, power factor, current, and temperature, as well as recording average temperature data for the test period. Synertech is in the final stages of developing such an instrument, which will be microprocessor-based and in a package that is smaller than the W-120. This instrument will substantially improve the usefulness and cost-effectiveness of field data, allowing analysts to have better information on both apartment temperature and refrigerator performance. It may also be useful for this program and for NYCHA's other interests to perform some longer-term monitoring of a sample of apartment temperatures in many of their buildings using dedicated data loggers.

Resident Education. There is widespread use of ovens to supplement space heating even in apartments which already appear overheated. In addition to wasting natural gas in the oven and lowering the efficiency of the often-adjacent refrigerator, such use of ovens can lower indoor air quality to the point that it becomes a danger to health. Developing a new set of resident education brochures which stress the proper operation, maintenance, and control of the new Maytag unit--along with tips for saving energy and maintaining indoor air quality--would be useful. Of course, lower control settings and lower apartment temperatures after new refrigerators are installed would result in longer life for the refrigerator as well as energy and demand savings and overall project cost-effectiveness. Working with resident groups in these efforts is always good policy.

Toward the Longer Term

The option of changing out only the high users first is not politically or logistically practical in NYCHA apartments. It is therefore appropriate to do the best job possible of changing out the oldest units first. Over the five to nine years projected for the project, this will translate into steadily increasing savings.

Delay in implementing 1998 standards will not be in the interests of this project or of the nation. Further, there is little hope for upgrading the procedures through which refrigerator efficiency is determined (the "DOE test"). Thus, other means are necessary to prompt major manufacturers to upgrade their products. Perhaps several of the testing methodologies developed in the first year of this project could be used in developing more detailed specifications for RFPs for future bulk purchasing agreements. The insights of the Lawrence Berkeley Laboratory team that developed the initial set of testing procedures should be sought in this and related matters. In all events, such improvements as smart dampers and improvements in cooling system COP should increase energy efficiency very cost effectively. Of course, it would be useful to apprise the research, bulk purchase, and supply communities of these opportunities.

TECHNICAL TRANSFER: SOME RECOMMENDATIONS FOR OTHERS

This has been a trail-blazing effort, and much has been accomplished that should be of use to housing authorities and other bulk purchasers of refrigerators. If refrigerator replacement programs can be cost-effective in the complicated circumstances that prevail in New York City public housing--particularly given the low rates charged for electric energy by the New York Power Authority--similar programs should work elsewhere. The discussion in this section is meant in the spirit of sharing practical wisdom with others who might contemplate establishing similar programs. For convenience, the audience we have in mind is primarily staff of public housing authorities, although many others interested in various aspects of energy efficient refrigerator programs may find some of the following observations useful.

New energy-efficient technologies are being developed all the time, but the development of a household appliance which uses two to three times less energy than existing units is genuinely extraordinary. Since refrigerators operate continuously, saving electricity 24 hours a day can have substantial impacts on the nation's grid. That is why the Department of Energy and the Department of Housing and Urban Development are enthusiastic in their support of refrigerator replacement programs by public housing authorities (and others). Except in rare circumstances (e.g., very low utility rates or a stock of existing refrigerators which meet or exceed 1991 standards) refrigerator replacement programs are likely to be cost effective.

Toward getting started, it may be useful to do some back-of-the-envelope planning to test possible cost effectiveness. If the refrigerators are purchased in bulk, and logistics are carefully planned, it is possible to secure and install energy-efficient refrigerators while recyling old units for a cost of $400 to $450. If annual apartment temperatures are not extraordinarily high and energy education accompanies the project, it is safe to assume annual consumption of the new unit will be 450 kWh/yr. To project annual energy costs with the new refrigerator, multiply 450 times the energy costs ($/kWh) from your supplier of electricity and add it to 0.65 times the demand cost ($/kW). Then, take a sample of the existing refrigerators and look up their annual consumption in the AHAM directory, weighting the number by your best estimate of the numbers of each model type in your apartment complex. The result times the $/kWh rate from your supplier of electricity gives energy costs for the existing stock of refrigerators. Demand costs may be estimated by multiplying annual kWh estimated usage by 0.00145 times kW demand cost.[1] The sum of the annual costs for the existing refrigerators less the sum of the projected costs for the new units equals estimated annual savings in dollars. Dividing this figure into the cost figure yields an estimate of the simple payback period. Anything less than 10 years is likely to be of interest to all parties.

An example will help. Assume your housing authority will be able to bulk purchase Maytag 15-cubic-foot units and secure an agreement with a recyler to take care of installations, removals, and recycling for a full cost of $410 per unit. Your utility charges 10 cents per kWh plus $18 per kW for demand. Thus annual cost of electricity for the new units is 450 kWh/yr x $0.10 = $45.00 for energy plus 450 kWh/yr x .00145 x $18 = $11.75 for demand, a total of $56.75 per year. Your survey of existing refrigerators yields an estimate of 976 kWh/yr for the average of them all. Thus, the cost of energy for the existing units is 976 kWh/yr x $0.10 = $97.60 and demand is 976 kWh/yr x .00145 x $18 = $25.47 for a total of $123.07. The estimated savings are 54 percent, or $66.32 per year. In this case, the simple payback should be approximately $410/66.32 = 6.2 years. This is a number you use as the basis for planning a concrete refrigerator replacement project; this is a number you can take to HUD.

There are many organizations and people you can turn to for help in launching a project. A useful list is included in Appendix A, people who were involved in various aspects of the present project, from planning, financing, and management to operations, recycling, and evaluation. Of note, the Consortium for Energy Efficiency in Boston has been tasked by DOE to help in overall technology transfer of refrigerator replacement programs.

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[1] Estimates of hourly demand assume an 8766 hour average year and a peak which is 1.06 times average. Since demand savings are monthly, the figures given are multiplied times 12 to reflect annual estimates.

Other important matters that should be considered in planning and operating a refrigerator replacement program are discussed below.

Critical Ingredients. Good managers with a sense of mission are critical to project success. As illustrated in the discussion of projecting cost effectiveness, a large supply of inefficient old refrigerators, access to efficient new ones at a good price, and high utility costs are important, too.

Planning. It is critical to envision all aspects of a project as complicated as a refrigerator replacement program and good planning is an essential ingredient of good management. When vendor agreements are secured and logistics established, it is critical to set up some form of management information system so that daily activities can be planned and tracked. Further, a system for evaluation must to be planned at the outset of the project and implemented. Our plan for conducting the first year evaluation work may be a useful reference; it is reproduced in Appendix B of this report.

Advisory Committee. Forming a committee of representatives of all organizations involved in the project was helpful in planning, tracking progress, and solving problems. We found that regular meetings, with all involved in the project reporting on their areas of responsibility, were helpful. Circulating draft planning documents, brochures, updates on progress, and the like, keeps all parties involved and improves the product.

Logistics and Management. In day-to-day operations, it is critical to deal with building managers and members of their staffs who work with residents. For example, a team of NYPA and NYCHA people met with the supervisor and key staff of each new complex several weeks before starting replacements. This facilitated making appointments, gaining access to apartments, and making mid-course corrections when necessary.

Residents. A good project brochure is helpful in explaining the program to residents, inviting their cooperation, and urging them to take concrete actions to conserve energy.

Working with resident groups is usually the best approach to communication with residents.

Hardware. Picking the right new refrigerator is critical to success. At present, we believe the new 15-cubic-foot Maytag is the best unit of its size--at least from the standpoint of energy use and cost--but field testing will be performed to learn more about this unit. Attention to control settings may be critical to ensuring energy-efficient performance while maintaining food as cold as it should be to safeguard health.

Measure Actual Performance. The only way to quantify savings accurately is to measure the performance in the field of both old and new refrigerators. The AHAM directory lists the energy performance of many units, but in practice less than half the old refrigerators removed in the first year of the NYPA/NYCHA project were both listed in the directory and had DOE test figures available. In all events, DOE test results are recorded for new refrigerators, not older units. It is important to measure the actual performance of examples of prevalent older models. Finally, as pointed out above, it is important to track ambient temperature over the period of the field test, the duration of which should be at least two days and preferably longer.

Being Choosy. The New York City public housing refrigerator replacement project had to be set up to change out all refrigerators in a building as a single operation. However, it may be possible to change out only a subset of the refrigerators, in which case choosing high users makes the best sense. How to choose then becomes a key issue. Some (not all) older, manual-defrost units have surprisingly low consumption and may be expected to last for decades. To make good decisions concerning which units to replace, some combination of records inspection (if models of refrigerators and dates of installation are available), direct inspection (looking up model numbers in the AHAM directory and assessing the present state of wear and performance), and short-term measurement should be implemented (Kinney 1996).

Section 7

REFERENCES[1]

Brown, S. and Wisniewski, E., 1996, "Inducing Efficiency Via Collaborative Purchasing: An Examination of Conditions for Success." Proceedings of the 1996 ACEEE Summer Study on Energy Efficiency in Buildings, American Council for an Energy-Efficient Economy, pp. 3.33-3.36.

Cochran, W. G., 1977, *Sampling Techniques*. 3rd ed. New York: John Wiley & Sons.

Cochran, W. G., 1980, *Statistical Methods*. 7th ed. Ames, Iowa: The Iowa State University Press.

Dutt, G., Proctor, J., and Blasnik, M., 1994, "Large Scale Residential Refrigerator Field Metering." Proceedings of the 1994 ACEEE Summer Study on Energy Efficiency in Buildings, American Council for an Energy-Efficient Economy, pp. 2.77-2.86.

Feist, J., et al, 1994, "Super Efficient Refrigerators: The Golden Carrot from Concept to Reality." Proceedings of the 1994 ACEEE Summer Study on Energy Efficiency in Buildings, American Council for an Energy-Efficient Economy, pp. 3.67-3.75.

Kinney, L., 1996, *Refrigerator Replacement Demonstration Project: Preliminary Results of Pilot Tests of Two Scenarios with The Rochester Gas and Electric Company*, Synertech Systems Corporation, SYN TR 96-528.

Kinney, L. and Stiles, M., 1994, "Refrigerator Monitoring System Development and Field Testing Results." Proceedings of the 1994 ACEEE Summer Study on Energy Efficiency in Buildings, American Council for an Energy-Efficient Economy, pp. 2.205-2.210.

L'Ecuyer, M., et al., 1992, "Stalking the Golden Carrot: A Utility Consortium to Accelerate the Introduction of Super-Efficient, CFC-Free Refrigerators. Proceedings of the 1992 ACEEE Summer Study on Energy Efficiency in Buildings, American Council for an Energy-Efficient Economy, pp. 5.137-5.145.

Nolden, S. L. and Morgan, S. J., 1996, "Super-Efficient Refrigerators for Apartments: The NYPA/NYCHA Project as a New Market Transformation Model." Proceedings of the 1996 ACEEE Summer Study on Energy Efficiency in Buildings, American Council for an Energy-Efficient Economy, pp. 2.181-2.185.

Pratt, R. G. and Miller, J. D., 1997, *The New York Power Authority's Energy-Efficient Refrigerator Program for the New York City Housing Authority—Savings Evaluation*. Pacific Northwest National Laboratory, Richland, Washington.

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[1] Other literature relevant to refrigerator efficiency and related issues is discussed in the Annotated Bibliography in the first appendix of the Evaluation Plan reproduced as Appendix B of this report.

Proctor, J., Dutt, G., and Blasnik, M., September 1994, *Pacific Gas and Electric Company Refrigerator Metering--Part One, Energy Consumption Comparison.* Proctor Engineering Group, CA.

Ross, B. A., September 1991, *End-Use Load and Consumer Assessment Program: Analysis of Residential Refrigerator/Freezer Performance*. PNL report PNL-7656 UC-350.

Suozzo, M. and Nadel, S., 1996, "Learning the Lessons of Market Transformation Programs." Proceedings of the 1996 ACEEE Summer Study on Energy Efficiency in Buildings, American Council for an Energy-Efficient Economy, pp. 2.195-2.206.

Turiel, I. and Hakim, S., 1996, "Consensus Efficiency Standards for Refrigerators and Freezers--Providing Engineering/Economic Analyses to Aid the Process." Proceedings of the 1996 ACEEE Summer Study on Energy Efficiency in Buildings, American Council for an Energy-Efficient Economy, pp. 9.207-9.215.

Turiel, I., et al, 1990, "U.S. Residential Appliance Energy Efficiency: Present Status and Future Directions." Proceedings of the 1990 ACEEE Summer Study on Energy Efficiency in Buildings, American Council for an Energy-Efficient Economy, pp. 1.213-1.234.

Appendix A

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of the
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Appendix A

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Appendix B

Evaluation Plan

Synertech
Synertech Systems Corporation

SYN TD 95-554, Ver 1.3
June 1996

Evaluation Plan

for the

New York Power Authority/New York City Housing Authority Refrigerator Replacement Program

Prepared for

The New York State
Energy Research and Development Authority

Under

Agreement 3015-EEED-BR-94

by

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Michael Stiles, Consultant to Synertech

N.B. This version of this evaluation plan has benefited substantially from comments by readers of earlier versions. As we learn more, it may be modified in the light new findings. Hence, all readers are invited to comment on its contents. Please forward comments to Dr. Larry Kinney at the phone or address below.

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Table of Contents

Program Background

Introduction

This planning document was prepared for the New York State Energy Research and Development Authority (NYSERDA) in fulfillment of Task #1, Formative Evaluation Planning, Exhibit A, Statement of Work, under Agreement 3015-EEED-BR-94. The Statement of Work is attached to this document as Appendix D. The purpose of this Formative Evaluation Planning Document is to provide the technical, logistical, and administrative framework for providing program implementation and evaluation support to the New York Power Authority/New York City Housing Authority Refrigerator Replacement Program.

At the November 16, 1995 Refrigerator Replacement Program planning meeting, Norine Karins of NYSERDA described the role of NYSERDA and its contractor, the Synertech Systems Corporation. Program support is being provided by Synertech under contract to NYSERDA. NYSERDA is directing the work of Synertech with input from a broad-based Advisory Committee. Advisory committee members represent NYCHA, NYPA, NYSERDA, Planergy, Synertech, and U.S. DOE. Additional nominations to the Advisory Committee shall be subject to NYSERDA approval.

The remainder of this document consists of an overview of the NYPA/NYCHA program and describes the framework for collecting and analyzing critical refrigerator performance data to support this important initiative.

Program Overview

The New York Power Authority supplies electric energy to the 2,900 buildings managed by the New York City Housing Authority. Under a recently-signed electricity supply agreement between NYCHA and NYPA, the Power Authority has agreed to invest $38 million in energy conservation in NYCHA buildings with refrigerator replacements being the centerpiece.

Most of the 180,000 apartments in these buildings have older refrigerators which waste electricity, require manual defrosting, or both. These refrigerators typically have 12 or 14 cubic feet of combined cooler and freezer volume. In a joint effort involving many organizations, virtually all of these 180,000 refrigerators are being replaced with the most energy-efficient self-defrosting refrigerator/freezers available at the time of replacement. The plan is to change out roughly 20,000 units per year over a nine year period beginning with the units which are the oldest. The average age of the approximately 20,000 units slated for changeout in 1996 is 16 years.

Most of the units removed will be "de-manufactured" by Planergy, a recycling company hired by NYPA. Possible pollutants will be separated and dealt with in an environmentally-safe way, and Planergy's facility has been approved by NYPA's Environmental Department. Metals will be recovered for other uses. A small number (two to three percent) of newer, fully-functional units that are replaced will used in other NYCHA developments or be put into temporary storage (typically in the basements of NYCHA's buildings) for use as spares.

The new units installed will be 14 cubic foot refrigerators whenever there is adequate space in the kitchen. New 12 cubic foot refrigerators will be installed only when an apartment's kitchen will not physically accommodate a 14 cubic foot unit. Many of the units removed from service are "partial defrost" models--they require periodic manual defrosting of the freezer section. Therefore residents will benefit from new refrigerators which have larger cooling space, are frost-free, and use less energy.

It is possible to produce self-defrosting 14 cubic foot refrigerator/freezer units whose annual energy consumption is substantially less than 500 kWh, compared to installed models which are estimated to consume from 700 kWh to 1200 kWh. At present, the best units of this size that are widely available at bulk prices have an annual consumption of about 498 kWh according to the DOE test procedure.[1] However, owing to this NYPA/NYCHA initiative, Maytag Corporation, a major manufacturer of refrigerators, is planning to produce 14 cubic foot refrigerators that are at least 30 percent more efficient than the present (1993) DOE standard.

Indeed, through the New York City Program and the influence of other housing authorities across the county, project sponsors hope to both stimulate the market to and take full advantage of refrigerator design and manufacturing trends towards energy efficiency and environmental consciousness. (The new units will be as "environmentally friendly" as present technology allows--they will make use of refrigerants and insulation which do not harm the ozone layer, and will totally avoid the use of known carcinogens.)

The program is planned to be spread out over a number of years. Of course, the oldest and (most likely) the least efficient units will be replaced first. Later in the program, the replacement refrigerators will be more efficient than those presently available. Hence, it is hypothesized that achieved savings will be roughly constant during each period of the program. An important objective of the evaluation work described in this document

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[1] The "DOE Test" for refrigerator-freezer units with an automatic defrost system and without an anti-sweat switch requires that a unit be run with controls at their mid point with no food load with no door openings in a test chamber at 90°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 kWh consumed over this period is then normalized to a 365 day year. 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." See the *Federal Register* of August 10, 1982, pp. 34517-34529.

is to examine this hypothesis via field measurements, laboratory measurements, and simulation studies.

Energy Savings Through Energy Performance Contracting

How much energy (and money) saved by this program is of great concern. The U.S. Department of Housing and Urban Development (HUD) pays a substantial portion of the energy costs for public housing in New York City. Thus, HUD has an interest in lowering energy costs and is active in urging housing agencies to undertake sound energy-conserving projects--those that result in genuine energy savings.

Toward ensuring soundness, the mechanism of "energy performance contracting" has become popular over the last 15 years. Performance contractors--frequently called "Energy Services Companies (ESCOs) in the energy conservation business--put their money (or that of a third-party investor) on the line to install energy conservation measures they believe will be cost effective. Usually, they share with the user an agreed-upon portion of the resulting savings. Thus, all parties have strong incentives to produce good energy savings as cost effectively as possible. For the ESCO, this usually means maintaining tight management and fiscal control of all aspects of a conservation project.

Through a DOE-HUD initiative, both the U.S. Department of Energy (DOE) and HUD are active in urging Public Housing Authorities and others to undertake energy conservation measures via the mechanism of performance contracting. The legislative mandate is the Housing and Community Development Act of 1987, and the final program rule was published in the *Federal Register* of September 11, 1991.[2]

The Structure of the Deal

HUD pays for energy costs in its public housing projects via a mechanism which estimates consumption based on an average of actual consumption in the three years prior to the last year. This three year base period is ordinarily rolled forward each year to estimate consumption (and HUD payments) for subsequent years. As an incentive to housing authorities to enter into energy conservation projects, HUD allows the housing authorities to retain a substantial percentage of the utility cost savings each year of the performance contract. In particular, HUD will make payments for up to 12 years of savings when non-federal funds are used for efficiency investment.[3]

This works for the interest of all parties, particularly when savings are substantial.

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[2] A handy guide that describes a range of possible mechanisms of HUD incentives in support of energy conservation through performance contracting is entitled "Energy Performance Contracting for Public and Indian Housing: A Guide for Participants." It was written by a team at the Energy Division of the Oak Ridge National Laboratory in 1992.

[3] Final Rule, dated September 1991, pursuant to Section 118 of the Housing and Community Development Act of 1987.

NYPA is functioning as the energy services company for the New York City refrigerator replacement project. In the role of energy performance contractor, NYPA is financing the purchase of the new refrigerators and paying for the de-manufacture of the units removed. It is also providing engineering, project management and corporate services for the entire project. Under the deal structured with NYCHA, NYPA will be paid back its costs for materials and labor plus a modest management fee. Monthly payments are being arranged at an interest rate of six percent interest and over a period of ten years. NYCHA, for its part, has formed an agreement with HUD through which it receives full defrayment of its actual program cost, while HUD benefits from 100 percent of the lowered electric energy costs. After 10 years, HUD will be able to realize 100 percent of the savings of the program at no further cost.

In short, there are net positive consequences for all parties.

The Role of Other Organizations

Although there is substantial enthusiasm on the part of all parties for this trail-blazing project, refrigerator replacements were not the principal energy conservation measure envisioned by the framers of the DOE-HUD initiative, and there is little experience to rely upon. Indeed, it is only relatively recently that energy-efficient refrigerators at good bulk prices have become available, a necessary condition for a replacement program to be cost effective.

As a part of the planning process, in early 1995 NYPA entered into a small contract with EUA Citizens, led by Steve Morgan, to estimate the potential costs and energy savings associated with replacing refrigerators in NYCHA's buildings. EUA Citizens also characterized NYCHA's existing refrigerator stock, relying on information from the Association of Home Appliance Manufacturers (AHAM)[4] and replacement schedules as a part of this planning study. Additionally, EUA Citizens contacted housing authorities across the United States to quantify the total stock of 14 cubic foot refrigerators in hopes of attracting a major manufacturer to re-design and re-tool to produce very efficient units of this size.

The U.S. Department of Energy is conducting market research to speed the transition to energy-efficient refrigerators across the country. DOE supports the Consortium for Energy Efficiency in Boston which is active in promoting large-scale purchasing of energy-efficient refrigerators for housing authorities across the nation. The aim is to achieve both economies of scale and the best energy efficiency (consistent with the use of only environmentally-benign materials) possible. As noted, the Maytag Corporation has already responded positively to these initiatives, and retooling is underway.

[4] AHAM's 1995 *Appliance Information Reference* contains information on year of manufacture, size, and result of DOE testing in estimated kWh per year (when test information is available) versus manufacturer and model number for tens of thousands of refrigerator models.

However, how much savings will result from this first housing authority program in New York City is not known with adequate accuracy. Accordingly, the New York State Energy Research and Development Authority is supporting research and evaluation efforts to measure how much energy is actually saved by the new refrigerators. The Synertech Systems Corporation, developers of special purpose electronic hardware for monitoring refrigerators, was retained to perform evaluation work. Synertech's evaluation team has been joined by Rob Pratt of Pacific Northwest Laboratories (PNL), a national laboratory supported by DOE. Mr. Pratt is performing computer simulations to analyze sets of data from different models of refrigerators under various operating conditions. He is being aided by Jim Miller, a colleague at PNL.

The information will be used to study the costs and benefits of the program and to plan its next stages, as outlined in the Evaluation Plan which follows.

Evaluation Plan

Summary

We know a great deal about how refrigerators perform under strictly-controlled conditions, but less than we would like about the real world in which people open doors at unknown intervals, refrigerate warm foods, and have kitchens whose temperatures vary substantially both daily and seasonally. Moreover, we need to find out how much energy refrigerators use annually in much less than a year, both to get early data for management decisions and to avoid excessive monitoring costs. Accordingly, this evaluation design is intended to combine field testing with laboratory testing which simulates real-world conditions in a carefully-monitored setting.

Refrigerator testing will be accomplished in the field and in Synertech's environmental chamber, which can test up to four refrigerators at a time. It is estimated that there are 30 models of refrigerators of which there are at least 100 in NYCHA's housing stock. Examples of models for which there are a large number of existing refrigerators will be tested in the field using an 11 channel data logger for two, week-long periods. (Although the current version of the project statement of work requires the testing of only a single new refrigerator, some of the same units tested in the field can be re-tested in the laboratory under the same conditions observed in the field, then re-tested at different ambient temperatures. The result would be a curve that relates energy consumption to ambient temperature for each model.)

Between January and August of 1996, Synertech technicians will monitor 218 existing refrigerators (a one percent sample). The aim is to match testing as well as practical to the proportion to the number of refrigerators of each model which exist in the NYCHA buildings where changeouts are scheduled to occur in 1996. In the case of 200 existing refrigerators, monitoring will be accomplished with a very accurate watt hour meter, with spot checks of temperature and voltage taken at the beginning and end of the week-long monitoring period. In the case of 18 others, measurement will be accomplished with the 11 channel refrigerator data logger.

During the same period, Synertech technicians will monitor at least one new G.E. refrigerator in the test chamber and 9 in the field using the 11 channel data logger, plus 20 new refrigerators using watt hour meters. Testing protocols will be at least as extensive as those associated with existing refrigerators.

Synertech will develop a training notebook based on field experiences and will hold a day-long training session early in June of 1996 for an audience of approximately 10 staff from NYCHA and NYPA. Divided between classroom and the field, the aim of the session will be to make sure all attendees can follow data collection procedures for field testing refrigerators using the watt hour meter and associated equipment.

Throughout the program, Synertech will gather best-known information on apartment temperatures. This will be aided by existing information from NYCHA on wintertime samples of apartment temperatures and supplemented by temperature readings taken during shoulder seasons and the summer by representatives of NYCHA and others in the research community.

Key inputs to the analysis are the thermal performance of the refrigerators as determined by the data logger, the average consumption of a larger group of refrigerators as determined by the watt-hour meter, and best-known ambient temperatures throughout the year. This information will be analyzed to estimate annual savings by refrigerator type. It will then be weighted by numbers of each type replaced to estimate total savings for the program.

Many indices of performance will be derived from the testing and revised as more data is gathered. For each refrigerator model, existing and new, principal indices will be best-current estimates of annual energy use (kWh) and hourly power demand (kW), along with energy and demand costs. Information on number of each model replaced will be used to produce running totals of savings of energy and money.

Regular reports will be made to the advisory committee on all project findings via monthly reports and committee meetings. A total of five advisory committee meetings will be conducted throughout the project. Recommendations for any mid-course corrections in the program (if needed) will be discussed at these meetings.

Best-known information from monitoring and analysis will be supplied to NYSERDA and NYPA for use in preparing new Customer Installation Commitment (CIC) documents and in revising existing CICs in light of new refrigerator performance data. This will occur at approximately two month intervals throughout the program. In addition, Synertech will make available to NYPA and NYSERDA its master data base reflecting the results of all refrigerator testing.

A final report will be prepared which reflects key project activities and findings, and presents concrete strategies for effective information dissemination to public housing authorities both within and outside of New York State. The report will be circulated in draft for comment by members of the advisory committee before being finalized in the light of comments received.

Introduction

Refrigerators are more than an insulated box with a cooling system; they are surprisingly complicated devices. In addition to a heat pump with a compressor which uses energy, there are systems with fans and dampers to move and control cold air and as many as six electric resistance heaters, from light bulbs and anti-sweat heaters to defroster coils. When they use refrigerators, people open doors that may represent more than 20 percent of the surface area of the insulated box, allowing warm moist air to replace cold air. More importantly, people insert warm masses of drink and food, the latter of which may not be covered. In consequence, the refrigerator has to work harder to deal with the latent load and the stored food has its moisture--as well as some of its freshness and taste--removed.

All of these factors affect energy consumption. However, in the case of refrigerators, an important determinant of energy performance is the ambient temperature of the environment adjacent to the refrigerator. Based on preliminary field studies conducted by the Synertech Systems Corporation in New York and Alan Meier of Lawrence Berkeley Laboratory and John Proctor of Proctor Engineering in California, a change of 5°F in the ambient temperature to which a refrigerator is exposed can change by 12 to 22 percent the amount of energy consumed by a refrigerator.[5] This single fact complicates considerably the job of evaluating refrigerator performance. If, for example, a refrigerator is tested for a week during the winter at average kitchen temperatures of 70°F, it may well use 35 percent more energy in mid summer when the average kitchen temperature is 78°F. Hence, if one ignores the effect of ambient temperature, annual estimates of performance based on a week's testing could be in error by 15 percent or more.

Directly related to this issue is that of control setting. Changes in control settings affect the temperature within the refrigerator, and whence the difference in temperature between the inside and out. This appears to be a fundamental determinant in energy performance of most domestic refrigerators.

Although many investigators have observed the important role ambient temperature plays in refrigerator performance, there is nothing resembling a data base which tabulates energy consumption versus ambient-refrigerator interior temperature difference for various models of refrigerators, particularly old ones. In short, although we know that there is a strong correlation between consumption and ambient/refrigerator ΔT, we do not know the slope of the curve. Yet, that is precisely the information needed for the evaluation stage of this project.

[5] See the annotated bibliography in Appendix A for full references. Both the LBL and Synertech work included testing in Upstate New York. Most of the Proctor work was accomplished in the Central Valley area of California which is characterized by quite warm summers.

These observations relate to another important fact relating to the DOE testing procedure. As noted in footnote 1, this procedure is conducted with empty refrigerators whose doors are kept closed in an environmental chamber held at 90°F. The rationale for the procedure is that door openings and food loadings are difficult to control from test to test, and that the higher-than-normally-expected temperature in the test chamber will tend to compensate for door openings and food loadings. This is undoubtedly true. However, in field work conducted by Synertech in New York and Proctor Engineering in California, refrigerators tend to perform in the field at least 10 to 15 percent better than predicted by the DOE test, particularly when ambient temperatures are around 70°F or colder. Depending on annual ambient temperatures and control settings, this suggests at least some possibility that the General Electric refrigerators which are the replacement units during the first year of the New York City changeout program **may** be found to use on average only 425 to 450 kWh per year rather than their DOE-test-rated 498 kWh.

Measurement Tools

As part of its mission to promote and foster energy efficiency in residential buildings, the New York State Energy Research and Development Authority (NYSERDA) has contracted with the Synertech Systems Corporation to conduct field measurements and perform analytical functions associated with refrigerator performance. Realizing both the importance of measuring the performance of refrigerators in the field and the absence of electronic tools available for doing an adequate job, in the summer of 1993 NYSERDA contracted with the Synertech Systems Corporation to fill this gap. This prototype development work was partially co-funded by both Synertech and the Electric Power Research Institute (EPRI)[6]

The result was the development of two refrigerator monitoring systems: (1) the W-100, a digital energy meter that measures true watt-hours to the nearest watt-hour; and (2) the R-100, an 11-channel refrigerator data logger. The R-100 measures and records in time series data records: true watts; true watt-hours; defroster run time; door opening events and durations; and refrigerator, freezer, and local room temperatures.

Two auxiliary analog and two auxiliary digital channels may be used to measure data from other sensors. Electronic and mechanical hardware and special-purpose software for both on-site and subsequent analysis were also developed.

Both the W-100 and the R-100 will be used extensively on the NYC refrigerator replacement project, as described in Synertech's statement of work attached as Appendix D. Further details on each system are the subject of a short paper reproduced here as Appendix C.

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[6] EPRI supports research in a wide range of technologies related to the generation, delivery, and use of electricity. The Institute manages 1600 projects throughout the world. EPRI is funded through annual membership dues from 700 member utilities.

In addition, a Synertech-designed environmental chamber is being used on the project. Measuring 8 feet by 8 feet by 8 feet, the chamber is able to test up to four refrigerators at a time. It can maintain temperatures between 40°F and 120°F. For this project, the chamber has been instrumented with R-100 data logging equipment. It has also been equipped with a system for automatically opening and closing refrigerator and freezer doors using any pre-programmed pattern desired, including exactly the same pattern of opening and shutting employed by the tenants in whose apartment a given refrigerator was tested. The chamber has been operational since February, 1996.

Planergy's facility where refrigerators are being demanufactured is only five miles from Synertech's offices. Thus, the occasional delivery of a refrigerator at Synertech instead of to Planergy is easily accommodated.

Outline of Planned Refrigerator Testing and Analytical Activities

As discussed above, the principal problem faced by the evaluation team is how to estimate as accurately as possible the annual energy use of a refrigerator when the measurement period is limited to substantially less than a year. The proposed solution involves one to four week periods of measurement in the field with both the R-100 and the W-100. Although Synertech is presently contracted to conduct chamber tests of a single new refrigerator, the paragraphs below anticipate the need for some additional chamber testing. Details are outlined in the following steps:

- Coordinate all field testing with NYPA and NYCHA. (See Appendix B for a sample site schedule.)

- Measure the usage for a week in the field using the R-100 11-channel data logger. This captures temperatures, door openings, as well as power demand (kW) and energy (kWh) usage.

- Examine patterns of temperatures, door openings, and energy usage to study differences between daily and long-term use and to identify any large anomalies (e.g., long-term door openings; major loading of warm, massive liquids, etc.)

- Move the refrigerator to a test chamber. Set up conditions identical to those in the field, including door openings and ambient temperature. Install a food load of approximately 75 percent capacity, using frozen foods in the freezer and water and covered foods in the refrigerator, leaving an inch between food and shelves and sidewalls. After reaching stabilization, run the unit for a week (or a lesser time depending on the results of the study of daily versus long-term use) and compare the results to usage in the field. [Note: differences should reflect differences in patterns of food loading. Quantify the difference and use in developing a formal error analysis. (It is also possible that the effects of the trip from the NYCHA apartment to Synertech's test chamber will result in a change in performance. If there is any change at all, it is likely that the change will be **very** substantial, and the test of that refrigerator should be abandoned.)]

- Repeat the test in exactly the same way at several ambient temperatures above and below the average of the ambient temperature observed during the week-long field test. Use the results to construct a plot of energy consumption in Watt hours/day versus ambient/refrigerator ΔT, where the refrigerator temperature is a volume weighted average of the refrigerator and freezer temperatures.[7]

- Unload the food from the unit being tested, leave doors closed, and run the chamber at 90°F. Perform a DOE test on the unit by running it at steady state for 24 hours, or from defrost cycle to defrost cycle. Correlate the results with those from the above tests.

- Gather best-known information about seasonal variations in apartment temperature, refining estimates throughout the project. In addition to spot measurements during W-100 testing and longer-term testing with the R-100, temperature data will be sought from others who have conducted empirical research in New York City multifamily buildings. Finally, temperature data routinely gathered by supervisor staff in apartment complexes during winter months will be expanded to monitor temperatures in a sample of apartments during the shoulder and summer months. Best estimates will be used to apply to the model.

- Run this entire R-100 testing procedure at least twice for each model of refrigerator in NYCHA apartment buildings except for those models having less than 100 units installed. Analyze the results and perform a formal estimate of errors. Integrate these results with field test results from W-100 tests of 400 refrigerators.

- Run this entire R-100 testing procedure on four of the new G.E. refrigerators as installed in NYCHA apartments. Use the information on door opening patterns and ambient temperature to test four other new refrigerators in accordance with the chamber testing procedure outlined above. Analyze the results and perform a formal estimate of errors. Integrate these results with field test results from W-100 tests of 30 new refrigerators.

- Using data supplied by NYCHA, form a database by model of existing refrigerators consisting of all of the refrigerators in all of the buildings in which replacements are scheduled for the first year of the replacement program. Assume that a two percent sample of each model will be taken over the project using the W-100 watt-hour meter, a spot radiometer,[8] and a volt meter. Use the data base to define the absolute number of each refrigerator type to be tested in each building.

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[7] The net interior temperature = [(frig temp*frig vol) + (freeze temp*freeze vol)]/interior volume.

[8] A spot radiometer is useful in recording surface temperatures very quickly. In practice, the model used by Synertech allows for gathering and recording the high or low temperature over an area scanned. Experience in the field shows that scanning for the lowest temperature in the freezer and refrigerator produces readings that are quite close to data gathered by thermocouple-based sensors. The difference is that a scan may be accomplished in a few seconds, whereas the process of installing a thermocouple

- Revise slightly the existing W-100 protocol and associated software (see Appendix B) to include taking a sample of line voltage and percentage drop under a 15 amp load at the beginning and end of the test. Streamline the existing form to reflect NYPA rates and integrate the data collection form into the new data base.

- Using Synertech personnel in coordination with building supers and others, each Friday (or one or two other days in the week as necessary) collect data from 15 to 18 W-100's and install them in new apartments. Field check data for anomalies at each site. Examine statistics. Look closely at outliers, both low and high. (For these purposes, "outliers" are defined as data points that are more than two standard deviations from the mean.) Mark some outliers for testing with the R-100, if necessary to explain mysteries, either on site or after removal in Synertech's test chamber. While in the field, get data downloads from the one to three R-100's that will be in the field and move the data loggers to new apartments.

- Each week, input data from the past week's data collection, update the data base, and refine statistics on each model of refrigerator tested. Compile these with current results from chamber testing. Share results with project sponsors and advisory committee members.

- Work with Rob Pratt and his colleagues of Pacific Northwest Laboratories (DOE/PNL) in developing models for various cross set data analyses. Use this information to build and update the master data base (see below under reporting)

- Continue the process of field collection until Synertech personnel have collected good W-100 data on at least 200 existing refrigerators (a one-percent sample) and 20 new ones. (Here, "good" data means that there is no indication of measuring equipment malfunction or tampering, and that the results are consistent with physical possibility. In the event that a refrigerator measures a small percentage of expected, it will be tested for another period. If it measures 100 percent greater or more than expected, it will be tested in the field or in Synertech's test chamber to ascertain why. See above discussion of outliers.) It is expected that 70 percent of the field testing will be completed by the end of May, all of it by the end of September, 1996.

- Analyze statistics on refrigerator demanufacturing by model and building prepared by Planergy. Use this information to guide subsequent field testing to ensure that frequently-occurring models of refrigerators are fully sampled.

- Develop a brief training guide based on field experience over the winter of 1996 for teaching others the craft of field work and data entry associated with the W-100.

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affects the air temperature, so steady state temperatures are not achieved until five to ten minutes have elapsed.

Conduct a day-long training session for up to 10 NYCHA and NYPA personnel in the field techniques and test protocol associated with the W-100 In the second week of June, 1996. (See below under Training.)

- Present current findings at advisory committee meetings, which will be held at approximately two month intervals over the year long project.

Training
The training outlined above will be designed to equip selected staff from both NYPA and NYCHA to understand both the philosophy and practice of accomplishing refrigerator testing in the field and conducting subsequent analyses. The training guide will include a thorough discussion of the detection of--and appropriate techniques for dealing with--anomalies which can arise in the field. A day-long session is anticipated. It will begin with a two-hour session in the classroom (at NYPA) which will focus on demonstrations of equipment (the W-100, the R-100, and other electric energy-measuring devices and temperature sensors) and hands-on techniques for using them. Then installations will be accomplished in an apartment complex which is close to NYPA's offices in mid-town Manhattan. Finally, a third two-hour session will be held at NYPA to analyze findings, using both hand-held calculator and computer techniques. This session will include a discussion of special circumstances, hands-on work with the data base software, and an evaluation of the day's training session.

ANALYSIS[9]

This following relates the project's data-gathering activities with its analytical objectives. Like other sections, it is likely to be modified somewhat over time, reflecting experience and early results obtained from the field and from experiments conducted under controlled conditions.

The fundamental objective of the analysis is to

- **Develop accurate, defensible average annual savings estimates for the high-efficiency replacement refrigerators relative to the existing models replaced, bounded by known and reasonable levels of uncertainty.**

Implicit within this objective are several key issues that must be analyzed, based on input from the principal parties involved, knowledge of refrigerator operations gained from prior experience, and the results of other evaluations of refrigerator programs. These key analytic issues are:

[9] The primary author of this section of this Plan is Rob Pratt of PNL.

- Adjust the short-term W-100 data for the pattern of indoor temperatures experienced over the year;
- Develop average savings estimates for each model replaced;
- Account for the persistence of savings over time;
- Account for heating and cooling interactions, if any; and
- Verify that the replacement refrigerators perform as specified by the manufacturer.

The field monitoring activities outlined above describe a multi-faceted approach to estimating the savings in electrical energy and demand from the project. Fundamentally, this approach involves:

- Short-term metering of *in situ* loads on a sample (~10) of each principal model of existing refrigerator and for the high efficiency replacement refrigerators for a duration of one approximately one week (the W-100 data);

- Collecting snapshot data (at the beginning and end of the metering period) of key drivers for load, including room temperature, control settings, refrigerator compartment temperatures, and food loadings;

- Complementing the W-100 consumption data with much more detailed metering using R-100 data loggers to collect 15-minute interval data including ambient air, refrigerator and freezer compartment temperatures, door openings and durations, defrost cycles, etc.;

- Using R-100 data loggers and a controlled environment test chamber to provide DOE-label rating tests for the principal refrigerator models, to investigate the nature of outliers from the field data, and to determine the effect of key behavioral components of refrigerator consumption, especially ambient and compartment temperature effects.

These data will be the basis for the analysis.

A great deal of effort has been applied toward developing field procedures and a method for data acquisition. The work proposed below is for the development of systematic methods for organizing, analyzing, interpreting, and validating the collected data.

Much of the discussion that follows concerns the pre-retrofit sample of refrigerators. It is anticipated that most, if not all, of the proposed analytical methodologies can be applied to the replacement models as well.

ANALYSIS OF FIELD METERING RESULTS

Steps in the analysis include:

- Reviewing, consolidating, and pre-screening the data;

- Creating a data base for statistical analysis from the data sets deemed acceptable;

- Performing first-order correlations of refrigerator energy consumption with the variables recorded in the field; and

- Selecting data for a more advanced correlation analysis, leading to estimations of regression parameters and their error margins.

The results of the last step will be supported by data from the environmental chamber experiments (see below). The primary purpose of these experiments is to obtain engineering estimates of how energy consumption depends on certain variables under controlled conditions. These experiments will provide insights into the variability of field results based on physical characteristics of the sampled refrigerators--as opposed to randomly imposed variations due to normal operation in apartments.

These first steps thus represent the initial effort to make sense of the field data. They are reviewed in somewhat greater detail below, following some considerations of the sampling process itself.

Comments on the Sampling Process: Potential Bias

According to the field personnel, by and large participants in the metering study are selected by management at each site. Management telephones residents until a quota is filled.

An important criterion of selection relates to the security of the equipment being installed. Managers choose participants likely to be responsive to the testing procedures and responsible for testing equipment.

There are several problematic features of this selection process that should be tracked through the course of the project. Are the residents contacted in alphabetical order or by apartment number? In the former case, the selection process might be considered random --there should be no *systematic* relationship between resident name and refrigerator operating characteristics.

If calls are placed by apartment number, there may be a bias. Examples of such bias include higher daytime apartment temperatures due to a location susceptible to solar gain, size of refrigerator due to size of apartment, and so on.

Does the management target elderly or non-working residents to get participants who will be home all day? Are selections made in a single building of a complex, where indoor temperatures are higher or lower than in other buildings in the complex? Are there systematic preferences in refrigerator make and model that appear in the selected sample? These are some examples of bias factors that should be tracked.

While not all of these sources of bias can be taken into account, some effort should be made at least to keep anecdotal track of them. Specially tailored analyses may be pursued for gaining insights into the magnitudes of these bias factors.

Pre-Screening of Data

This is probably best performed after the meter data from an entire complex are collected and entered into an electronic format. One of the leading preliminary indicators is estimated annual consumption. This number is obtained by first extrapolating average energy consumption over the term of the test period to a full day's worth of consumption, then multiplying by 365.25 days per year.

The current rule of thumb is to deem annual consumption between 500 and 2,000 kWh per year an acceptable estimate. Conspicuously high and low values of estimated annual consumption will be examined with care. For the R-100 data, similar range checks will be conducted on the time series loads, as well on the other metered variables as appropriate.

At least a sample of refrigerators with outlandish measured consumption should be tested in the environmental chamber. Based on the results of examining each type of outlier, a protocol will be developed defining whether outliers of a given class should be eliminated from the analysis. Data that is recommended to be discarded will be flagged as such, but retained in the data base. Rates of such attrition will be tallied.

Preliminary analysis of the other field data can be accomplished by automated range-checking formulas programmed into an analytical spread sheet. This alerts the analyst to exceptional values quickly and efficiently. Similarly, the changes in the "snapshot" temperatures (i.e., final - initial) will also be examined. Major differences in starting and ending conditions will be assessed, ranked, and flagged.

Acceptable data sets will be entered into a master spread sheet having pre-defined fields, allowing for easy sorting and macro-based analysis.

The Data Base: Primary Field Data

The primary data are those recorded directly from instrumentation and audit procedures. They are distinguished from secondary or computed data, which are derived from the primary data.

The current data acquisition software records all of the primary data and performs a number of secondary computations. All of these data are stored in the field data base. However, most of the secondary data must be regarded as provisional at this time. For example, indices that adjust energy consumption for refrigerator volume and temperature conditions are their own subject of investigation and will be treated later in the project.

For present purposes, the primary field characteristics data on which all sorting categories will be based are shown in Table 1, with the primary measured data for both W-100 and R-100 field testing shown in Table 2.

Table 1. Primary Characteristics Data
Audit date
Site location
Sequence in audit
Customer name, address and phone number
Number of occupants
Name of electric utility
Utility rate (energy and demand)
Refrigerator characteristics:
Style
Mode of defrost
Manufacturer
Model and year
Whole-unit dimensions
Refrigerator and freezer dimensions
Food loading (% capacity) of fridge and freezer
Maximum depth of ice accumulation
Anti-sweat feature existence and use
Control settings and scales

Table 2. Primary Measured Data

	W-100 Sample	R-100 Sample (all 15-min.)
Consumption	Wh, cumulative (~ week)	Wh, 15-minute total
Date and time	snapshot (start & stop)	meter time-stamp
Kitchen temperature	snapshot (start & stop)	metered, avg. °F
Refrigerator temperature	snapshot (start & stop)	metered, avg. °F
Freezer temperature	snapshot (start & stop)	metered, avg. °F
Door openings, count	N/A	metered, interval total
Door openings, time	N/A	metered, interval cum. sec.
Defrost cycle, on-time	N/A	metered, interval cum. sec.
Temperature behind fridge	snapshot (start & stop)	snapshot (start & stop)
Compressor on/off status	snapshot (start & stop)	(implicit in consumption)

Modeling Temperature and Other Effects on Consumption

As discussed above, any savings estimate for refrigerators based on short-term measurements must control for the kitchen temperature. This is because kitchen temperature varies from day to night and from season to season within homes, and refrigerator performance is known to vary significantly as a function of temperature. A typical refrigerators' response to indoor temperature is shown in Figure 1. Refrigerator temperature response curves have been noted to be either linear or curved upward as in Figure 1. The shape of any such curve typically is often equally well represented by a curve or by two straight lines, as shown. This makes good physical sense, since the heat conducted through the refrigerator's insulated cabinet is proportional to the difference between the compartment and the ambient air temperatures. The curve may result in cooler ambient air temperatures that approach those of the refrigerator compartment, gradually reducing that compartment's load to zero with the total refrigerator load approaching that of the freezer compartment alone.

Because the consumption in the W-100 sample data represents that for a particular week of the year, it will reflect the kitchen air temperature that occurred during that week. Since kitchen temperatures are expected to vary widely over the course of the year as the outdoor temperature changes, this is a primary effect that must be taken into account before the W-100 can be used reliably.

In a recent study, two methods for characterizing refrigerator energy consumption have been used to take temperature into account (2,3). One method analyzes consumption of each refrigerator individually as a function of one or more independent variables. This method will be called the Individual Unit Method. The other method takes aggregated averages in order to characterize a "typical" refrigerator, and will be referred to as the Aggregate Method. We will try several variations on each method, compare the results, and recommend which should be used to quantify savings.

Both methods make use of multivariate regression analysis, wherein statistical determinations are made of the impacts of each of the variables that influence refrigerator energy consumption. One of the goals for this process will be an evaluation of which of those variables are most pertinent to characterizing energy consumption.

The Aggregate Method is useful because it provides a particularly simple way of representing temperature effects on a given population of refrigerators. In this approach, the consumption data is simply plotted as a function of the observed kitchen temperatures. Because the W-100 metering will occur over about half a year ranging from winter to summer, a range of kitchen temperatures will be observed. By fitting a separate line or curve through the data for the existing and replacement refrigerators, an estimate of the load at any given temperature can be made for the two groups as a whole.

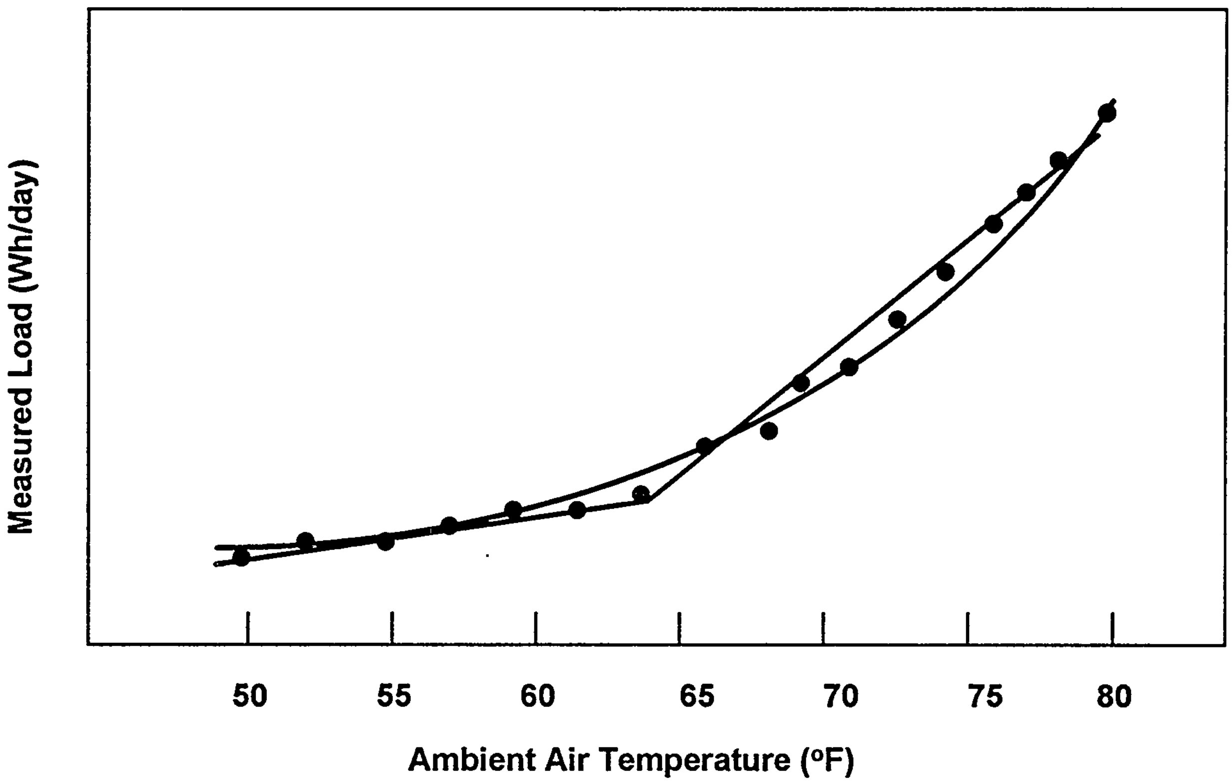


Figure 1. Typical Refrigerator Load Response to Ambient Air Temperature

It will be informative to compare results from small samples of the same type of refrigerator (probably using t-statistics) to estimate the magnitudes of these fluctuations *in situ*. Because of the variety of refrigerators encountered in the pre-replacement population, this method will be useful as a preliminary step before sorting results by make, model, and/or size.

Finally, estimated daily consumption will be plotted against other variables such as volume, food loading, ice frosting, internal temperature and kitchen temperature data. Trends in such plots will be sought by visual inspection and by statistical analysis. The most significant of these variables will become candidates for multivariate regression analysis.

Several important variations on the Aggregate Method will be investigated. Compartment-to-kitchen temperature differences will be examined to see if using this variable, which controls for both temperatures in a physically meaningful way, results in less scatter and improved confidence intervals of the results. It may also be possible to characterize the effect of individual models of existing refrigerators by fitting separate curves to each of them, when there are enough data points and temperature range to support such analysis. This may further reduce the scatter in the existing refrigerator data. Finally, other observed variables in the W-100 data will be investigated for their ability to explain yet more of the variance in the data.

The Individual Unit Method attempts to make use of the additional details provided by the R-100 sample data to adjust individual consumption observations in the W-100 data for observed temperatures and to control for other key variables. Fundamental to this approach is the attempt to separately characterize the physical performance of the refrigerators from the influence of the occupants. In the case of kitchen and compartment temperatures, for example, the R-100 data from the test chamber results can be used to develop a performance curve for each principal model of refrigerator, as shown in Figure 2.

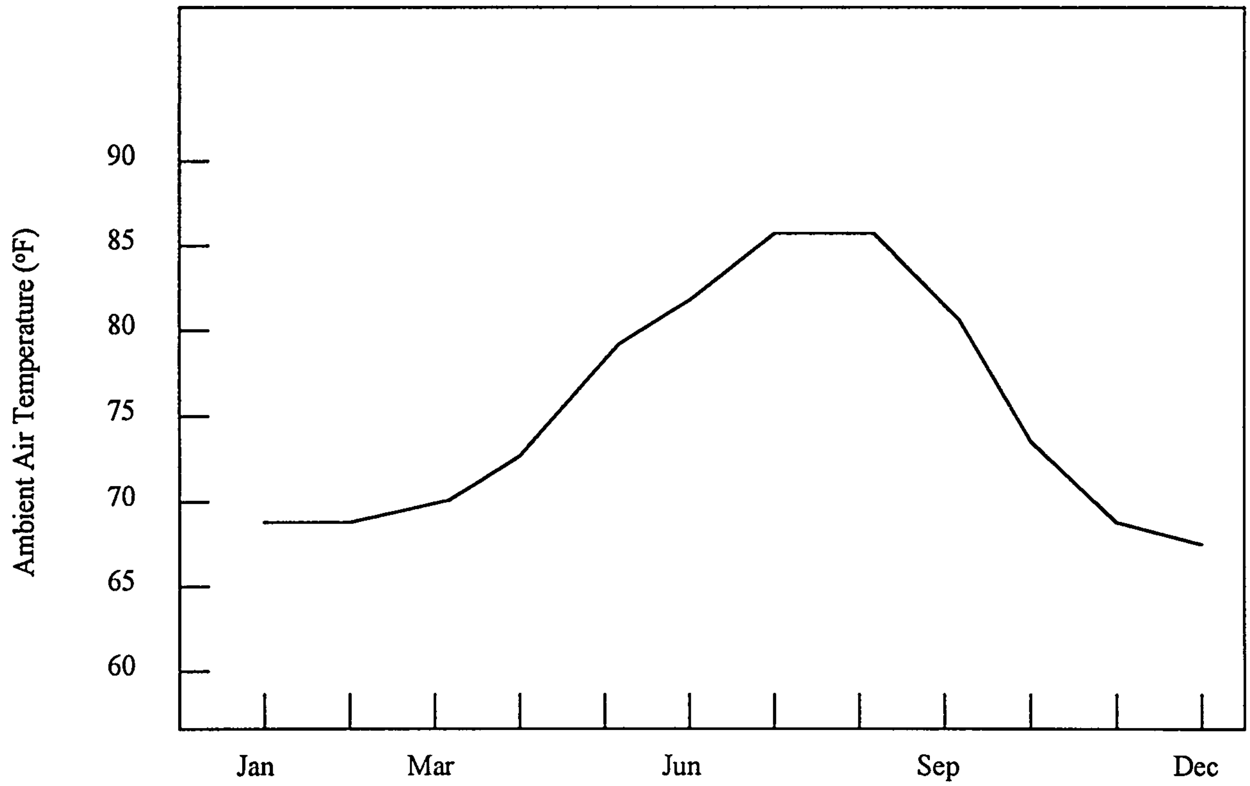


Figure 2. Average Monthly Indoor Temperatures (R100 Metered & W100 Snapshot Field Data)

The R-100 field data can be further analyzed to estimate the effect of day-to-night temperature changes in apartments. Since snapshot readings will nearly all occur when apartments are occupied, and will predominately occur during daytime and early evening hours, the observed snapshot kitchen temperatures will be higher than the true average. By creating 24-hour profiles of kitchen temperature using the R-100 data, an adjustment can be made for this as needed.

Then, the R-100 data from chamber and field testing can be used to develop temperature response curves for each model so tested, as shown in Figure 3. Using these and the sample average kitchen temperatures in Figure 2, each W-100 consumption measurement can be converted to 12 monthly load estimates, as shown in Figure 4, and summed to form an annual average.

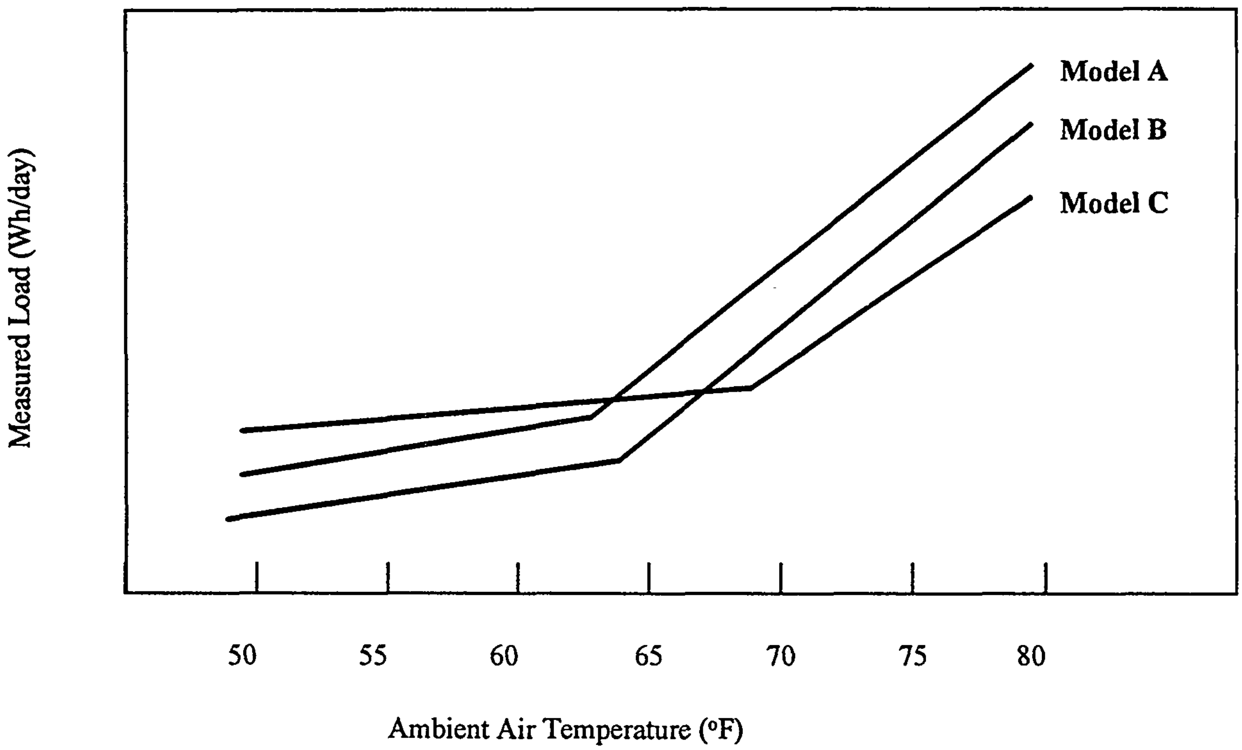


Figure 3. Model-Specific Temperature Curves (R100 Data)

Other occupant behavior indicators metered as part of the R-100 sample can also be analyzed by computing sample averages in a similar fashion. These include compartment temperatures and door opening counts and durations.

The types of statistical methods to be used in evaluating the models include ordinary least-squares, the standard error of estimate, the t-ratio, and comparisons with analysis using the method of general moments (2,3) and/or other alternative methods.

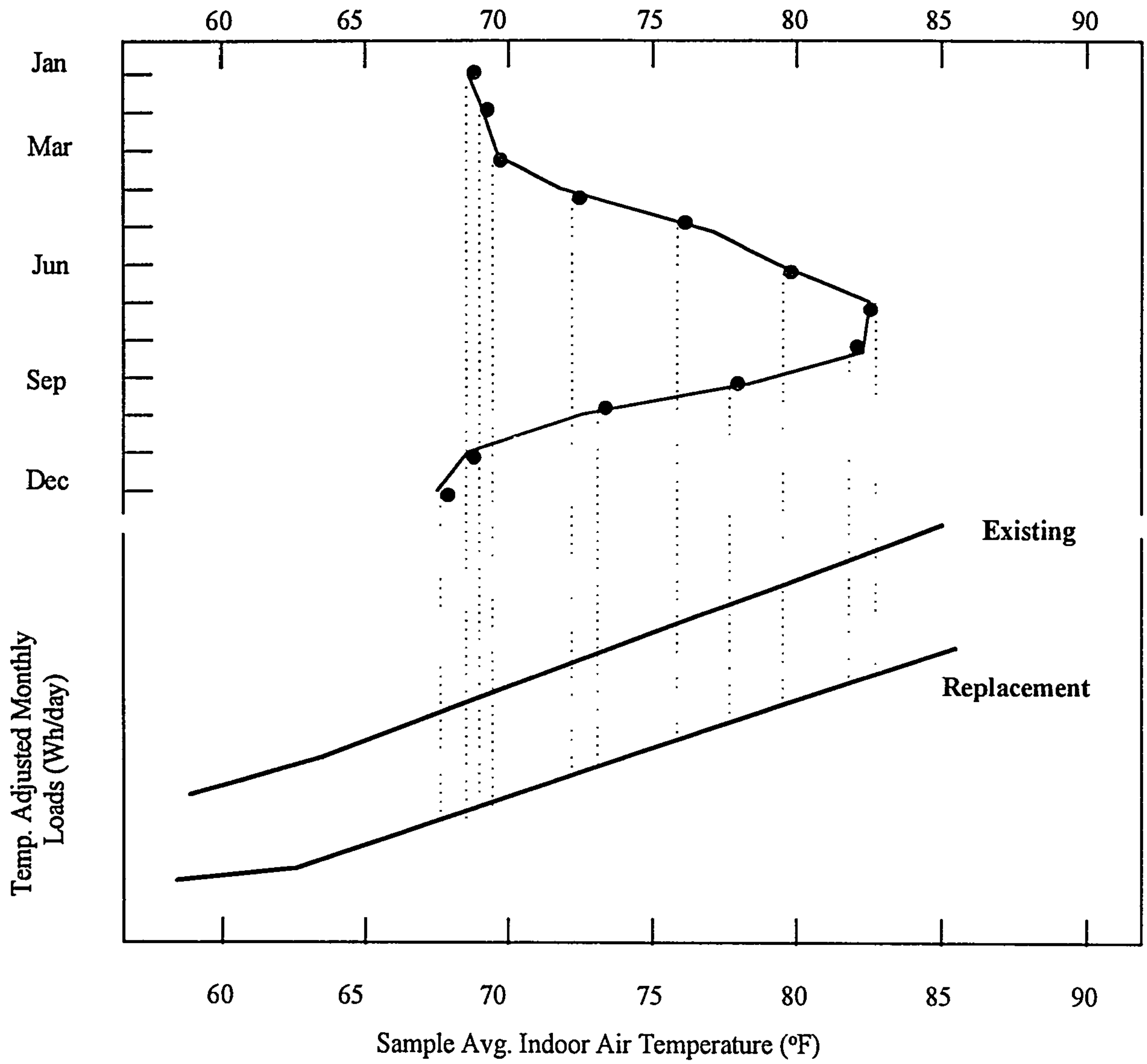


Figure 4. Monthly Temperature Adjustements

Persistence of Savings

The persistence of savings for the program must be accounted for in overall savings estimates. Hcwever, at this point there is little to indicate what these effects will be. Other studies have noted degradation of refrigerator performance over time. If the absolute rate of degradation is the same for the existing and replacement refrigerators, as seems reasonable to assume, then the difference between the consumption of the replacement refrigerators and the existing refrigerators replaced will remain constant over time, as shown in Figure 5.

Another consideration relates to possible changes in ambient temperature due to heating system balancing or the addition of other measures which might affect the thermal dynamics of NYCHA's buildings in the future. If old steam heating systems are in balance (which, according to research sponsored by NYSERDA, is the exception in New York City), average ambient temperatures in apartments can be reduced by two or more degrees F. Based on findings to date, a two degree diminution in annual average ambient temperature will result in a decrease of 25 kWh per year in the consumption of the new refrigerators.

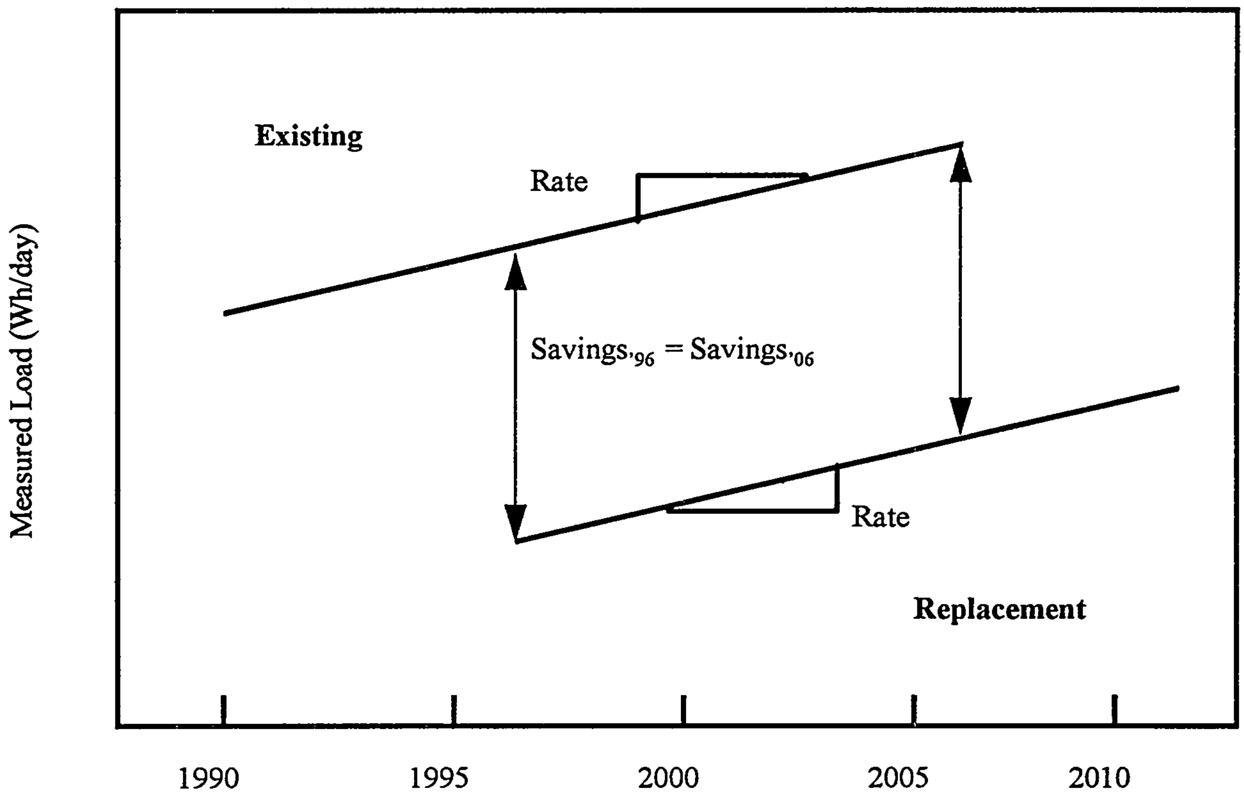


Figure 5. Effect of Refrigerator Performance Over Time on Savings (Assuming Equal Absolute Degradation Rates)

This assumption of constant absolute rates of degradation corresponds to degradation modes not affected by the relative efficiency of the refrigerators, such as door seal leakage. Loss of insulation quality, compressor efficiency, or heat exchange effectiveness may be better reflected in similar **relative** degradation rates, that is, by a similar percentage per year for both classes of refrigerator. Since the replacement refrigerators are efficient, their absolute degradation rate would then be smaller, in this case.

The project has two means of gathering further information in this area. First and foremost, this is a subject for study using spot metering of 1996 refrigerators in forthcoming years. Second, some attempt could be made to compare the label ratings of the old refrigerators with their performance in the R-100-monitored chamber tests. This would provide an estimate of the actual degradation rate of the existing sample, but obviously would not help with the replacement sample.

Heating/Cooling Interactions

We are proposing that there are not substantial heating and cooling interactions due to the reduced level of heat given off by operation of the replacement refrigerators. These interactions are in the form of increased winter heating loads and decreased summer cooling loads. This is because apartment temperatures are generally not controlled by individual thermostats, but rather are set for the building as a whole. It is unlikely that these settings will be reduced from current levels as a result of this program. Most apartments are not air conditioned, so cooling interactions will be small. Given the uncertainty in quantifying this effect, the additional expense for data collection and analysis does not appear worthwhile for this class of multi-family building.

Environmental Chamber Experiments

As indicated in Synertech's current statement of work, the chamber testing envisioned is restricted to detailed tests of a single refrigerator. However, more extensive testing is likely to be useful for a variety of reasons. This section describes the rational for chamber testing and describes a series of tests

Based on previous studies, it has been concluded that there are two categories of factors that influence annual refrigerator energy consumption--temperature-related factors and non-temperature-related factors (2,3). As discussed above, annual temperature data is being gathered in several ways.

Non-temperature-related data, such as food loading and door opening behaviors, are harder to collect. However, the spot observations of field technicians and the detailed time-series records of the few R-100 monitoring cases could be extrapolated to the study's population.

There is a major issue in this study, as in previous studies: How important are the non-temperature-related factors in determining annual refrigerator energy consumption? The issue is compounded in this study by the many different makes and models that are being replaced. To address this issue, an environmental chamber was designed and installed at the Synertech Systems Corporation to test for a variety of factors in as many different types of replaced refrigerators as possible.

One of the most obvious experiments to perform under controlled conditions is with the temperature-related factors. This will provide a more complete view of how consumption is influenced by temperature differentials than the field data are likely to provide.

Another important use of the chamber will be to examine whether the variables assumed for multivariate regressions are truly independent. Combinations of temperature conditions, levels of food loading, and so on can be tested under controlled conditions. The results of these tests can be compared to predictions from the statistical models, for validation.

At a minimum, two types of investigations will be conducted. These are described below. Other experiments may be suggested and conducted during the course of the project, especially for refrigerators that give anomalous field data.

Environmental Chamber Interactions

The chamber can test up to four refrigerators at once. It is important to establish that they do not affect each other's performance. The test is fairly straightforward and will be conducted as a one-time experiment. A single powered but empty refrigerator will be tested under constant temperature conditions for at least a few hours. There will be no door openings during this time. Using the R-100, the average and standard deviation of the energy consumption will be computed.

Three more refrigerators will then be set up and powered in the chamber. The test will be repeated, and the new average and standard deviation of the first refrigerator's energy consumption will be computed.

A z-score analysis will be used to determine the probability that the additional refrigerators significantly changed the average energy consumption of the first. In the unlikely event that a significant difference is found, steps will be taken to estimate the magnitudes of interactions in all subsequent experiments.

Refrigerator Performance Testing

The following is a description of a series of tests conducted in the controlled test chamber to quantify key aspects of refrigerator performance. The steady-state load tests that are the basis of many of the tests discussed below are all based on equilibrium conditions. These are defined as follows:

- The test is initiated when steady-state conditions have been reached, defined as eight consecutive 15-minute intervals in which the average refrigerator compartment temperatures do not vary by more than 4°F and whose total load (Wh) does not vary by more than +2%. (These constraints assume no defrost period.)

- Alternatively, using 1-minute data these are defined on the basis of three consecutive compressor cycles occurring at the same interval (+1 minute) during which the average compartment temperatures do not vary by more than + 2 °F

The load test consists of the total consumption (Wh) from the end of one defrost cycle to the end of another, with the annualized load computed from

Annualized Load = 8766 (hr/yr) * test load (Wh) / test period (hr)

DOE Rating Test

Procedure. [Follow DOE rating test as specified in 10 CFR-435.] Conduct steady-state load tests of an empty refrigerator, in a chamber maintained at 90°F, with the compartment temperature set to either the minimum or the maximum, and the mid-point between the minimum and maximum. The DOE label rating is the annualized load at the mid-point temperature adjusted by linear interpolation to a 5°F freezer temperature given that the refrigerator will be at 45°F or below when the freezer is at 5°F.

Key Result(s). In existing refrigerators, the DOE rating can be compared to the manufacturer's rating (when available) to estimate performance degradation and/or manufacturing variation. In the efficient replacement refrigerators, the DOE label rating can also be used to assure that the purchased refrigerators are as efficient as claimed. The DOE test also provides load estimates at three compartment temperatures, supplementing the ambient temperature test.

Ambient Temperature Test

Procedure. Conduct steady-state load tests of an empty refrigerator, with the compartment temperature set at the mid-point from the DOE test, and with the ambient temperature at 60°F and 75°F. If a DOE test has not been conducted, set the compartment temperature as close to the physical midpoint of the dial setting as possible and add a third test at an ambient temperature of 90°F.

Key Result(s). The result of the ambient temperature test is to determine the load as a function of the ambient to compartment temperature difference. By plotting points from the DOE test on this same curve, the degree to which the load is determined by the primary effect of the temperature difference driving the compartment heat loss as opposed to the secondary effect of the source and sink temperatures on the compression cycle COP.

Door Opening/Food Loading Test

Procedure. Conduct a steady-state load test at 75°F and with the refrigerator and freezer compartments loaded with a known quantity of "food." Then, conduct a test in which the refrigerator door is opened for 20 seconds duration once, five times, and ten times during a time period corresponding to three normal compressor cycles with steady-state conditions reached between each one. Record the resulting load and compartment temperatures. Repeat this test at 90°F. Then repeat the entire test for the freezer compartment door.

Key Result(s). These tests will indicate the degree to which door openings influence the refrigerator load, including the effects of number of openings, duration of openings, and the food loading. The results will be used to help form the models of refrigerator consumption as a function of these variables. For example, we anticipate that when food is loaded the consumption will be lower than for an empty refrigerator, since there is less residual volume for air exchange. Conversely, we might expect that extra consumption is lower as a function of door opening duration when there is no food loaded, since there is less mass to absorb heat.

Transient Test

Procedure. This is a three part test. First is a decay test. With the refrigerator empty and the ambient controlled at 75°F, turn off power to the refrigerator and observe the temperature decay until it the compartment to ambient temperature difference has decreased to 37% of its initial value. Note the time required for this to occur, the time constant. Re-apply power to the refrigerator and allow it to reach steady-state conditions with a known volume of water in the refrigerator compartment. When the refrigerator/water combination are at steady state, conduct a second cool-down test.

Key Result(s). The primary function of these tests is to attempt to estimate the compartment heat loss coefficient (UA) and the compression cycle COP. The slope of the temperature curves from previous tests is equal to the ratio of these quantities (UA/COP). The additional consumption during the cool-down test should be almost entirely due to the energy change in the water, and is

Load (steady-state) - Load (cool-down) = (mCp)H2O * (TH2O - Trefr) / COP

where (mCp)H2O is the specific heat capacity of the water, TH2O is the initial temperature of the water, and Trefr is the refrigerator compartment temperature.

The two decay tests produce two time constants

t1 = UA * (mCp)refr

t2 = UA • [(mCp)refr + (mCp)H2O]

Since the heat capacity of the water is known, this system of two equations and two unknowns can be solved to yield estimates of UA and (mCp)refr.

Both procedures can then be used with the slope of the temperature curve (UA/COP) to obtain an estimate of the COP or the UA, respectively. This distinction is important, since food loadings and door openings are affected by the COP only.

This procedure will be employed primarily on the new refrigerator so that elements which account for its efficiency may be estimated and compared with those of other energy-efficient models.

Usage Simulation Test

Procedure. This test simulates the *in situ* consumption of a refrigerator with a chamber test. The ambient and compartment temperatures are set as in the R-100 field measurements. A typical food load is installed, steady-state conditions are reached, and then the exact timing and duration of door openings measured in the field is repeated in the chamber, with the load recorded continually.

Key Result(s). The difference between the in situ loads in the field and the chamber loads should be the combined result of food cool-downs, different defrost cycling due to humidity differences, and kitchen arrangement effects (nearby oven/range usage and restrictions to air flow at the refrigerator coils). This test will be extremely useful to bound the magnitude of these effects as well as checking the nature of consumption outliers from the field tests.

Suggested Chamber Testing Samples

We propose that the entire series of tests be conducted on at least one existing and one replacement refrigerator. The existing refrigerator should have typical (not aberrant) consumption in the field measurements. Further, the DOE test and temperature effect test should be conducted at least three of the replacement refrigerators and as many distinct models of existing refrigerators as possible. Priority should be given to existing refrigerator models that are numerous.

Reporting

There are five kinds of reporting associated with the evaluation portion of this project.

(1) Monthly progress reports sent to project sponsors and members of the project advisory committee. These will consist of a narrative of principal activities and will occasionally include an appendix that describes a finding of special interest. Project reports will be consistent with NYSERDA reporting requirements under Agreement 3015-EEED-BR-94.

(2) Presentations on project activities and findings for review by sponsors and the project advisory committee and potential presentation to HUD.

(3) Information for presentation to HUD associated with actual savings.

(4) Information for presentation to representatives of housing authorities in New York State and elsewhere plus others. It is likely that some of the slides and hard copy prepared for review by the project advisory committee will be useful for this audience.

(5) A project final report, consistent with NYSERDA reporting requirements. This will describe in detail all project activities and key findings and contain recommendations for the future.

Quantifiable data included in the final report (and project presentations as appropriate) will be included in a master table from the data base showing:

Existing Refrigerators

- Numbers of each model of refrigerator which existed at the beginning of the project;
- A breakdown of refrigerator models by building;
- The number of units that have been removed and replaced to date (the current report);
- The number tested in the field to date using the R-100;
- The number tested in the chamber to date using the R-100;
- The number tested in the field to date using the W-100;
- The current best estimate of annual average ambient temperature in the apartments housing the model of refrigerator;
- The current best estimate of annual consumption of the unit (kWh);
- The current best estimate of the hourly demand of the unit (kW);

New Refrigerators

- The same set of data associated with the above nine bullets for the new refrigerator;

Savings

- The current best estimate of the kWh savings for each refrigerator model tested;
- The current best estimate of kW savings for each refrigerator model tested;
- The current best estimate of annual dollar savings for energy for each model tested;
- The current best estimate of annual dollar savings for demand for each model tested;
- The current best estimate of annual dollar savings for energy and demand for each model tested;
- Total annual dollar savings by model to date; and

- Total annual dollar savings to date.

Each of the above entries will be associated with standard deviations and other useful statistical indicators of the distribution of data as a function of the amount of data collected to date.

Portions of this master chart will be abstracted as appropriate for ease in presentation on both hard copy and slides. In addition, three other kinds of data display are anticipated at this point; no doubt others will arise as data are analyzed and feedback is received from the project advisory committee and others:

(1) Pie charts will be used to express data such as the portion of the whole represented by each model type. For example, the numbers of a given model for the first 4,543 refrigerators to be taken out of the first six buildings range from 1,242, a 12 cubic foot Whirlpool refrigerator installed in 1980 (27.3%), to 9, a 14 cubic foot Gibson installed in 1985 (0.2%).

(2) Nomographs will be used to plot consumption data collected in the field for each model and for the group of old refrigerators versus the replacement refrigerator. These give a nice visual display of the clustering of the data and allow for the quick assessment of the magnitude and extent of outliers. Overall N's (the total numbers of units represented in the plots), the standard deviation, the mean, and median of the distributions will be included with each nomograph.

(3) Two-dimensional plots will be used to show correlations between independent variables like ambient temperature and dependent variables like energy consumption. Line fitting and the display of correlation coefficients will be employed when the data support their meaningful use.

Finally, a set of tables of projected savings will be produced that reflect the best current savings estimates for all refrigerators replaced over any given period. It is anticipated that this table will be useful both to the current project and to other housing authorities interested in evaluating savings cost effectively. Using a combination of Microsoft Access and Excel software, these tables will indicate, by model and in total (weighted by the number replaced). These tables will include at least the following information:

- the number of refrigerators replaced
- the number of refrigerators measured
- the DOE label rating
- the mean measured annualized consumption
- the mean temperature-adjusted annual consumption estimate based on measured data
- the mean temperature-adjusted annual consumption estimate based on label rating
- the standard deviation and confidence intervals for the above

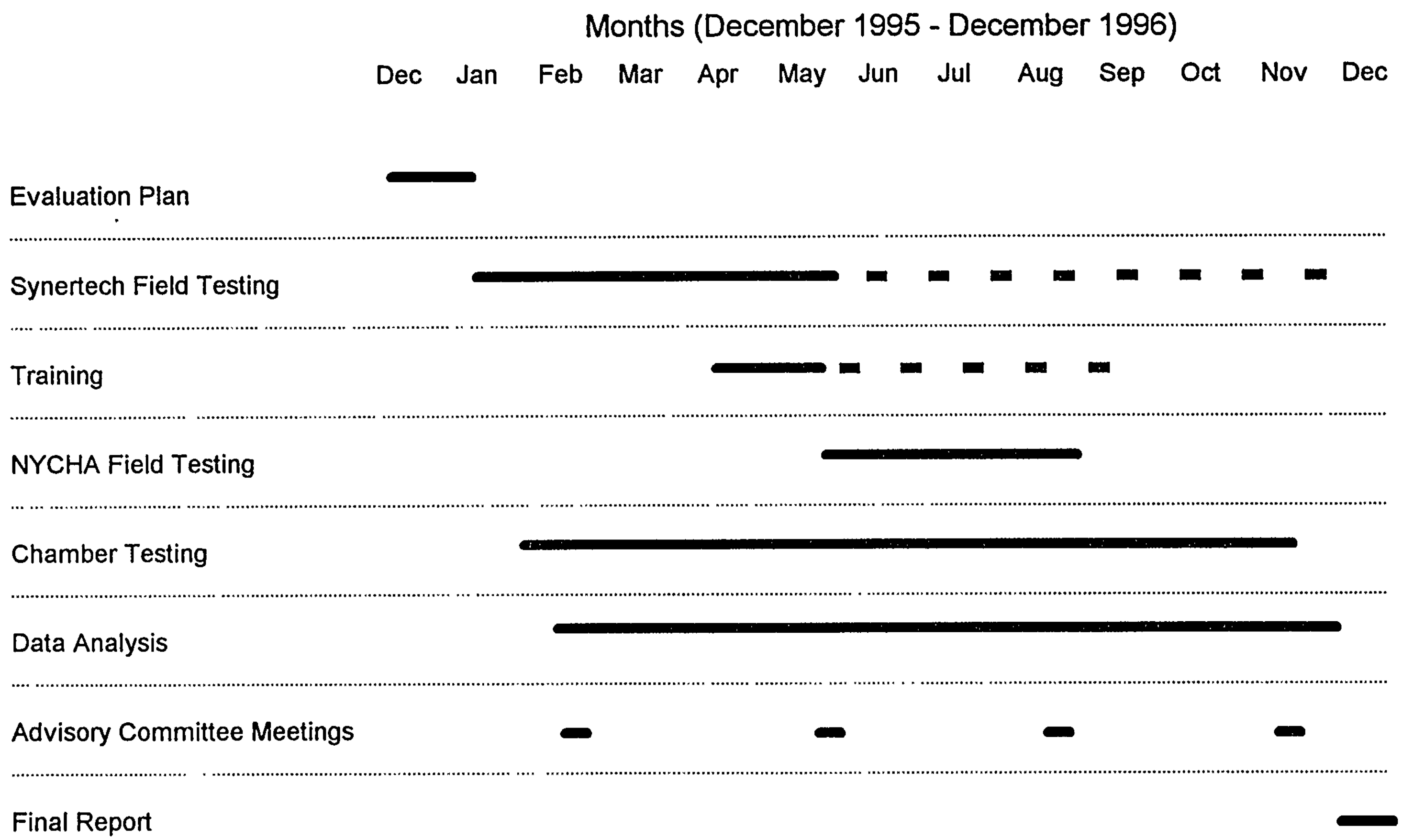
- the observed ambient, compartment temperatures

Data fields will be added to the database to indicate whether a given data point is to be used or not in the analysis. All temperature adjustments, data QA checks, and other data analysis processes will be included. The system will archive the replaced refrigerator counts so that updated tables reflecting current savings estimates using all available data can be produced at any time.

Clearly, the value of this table will increase with the number of observations available.

Project Timing

See the timing chart on the following page.



Project Timeline

REFERENCES

(1) Kinney, L. "Evaluation Plan for the New York Power Authority/New York City Housing Authority Refrigerator Replacement Plan (Version 1.1)," SYN TD 95-554, December 1995.

(2) Dutt, G., Proctor, J., and Blasnik, M. "Large Scale Residential Refrigerator Field Metering," Proc. 1994 ACEEE Summer Conference , pp. 2.77-2.86, 1994.

(3) Proctor, J., Dutt, G., and Blasnik, M. Pacific Gas and Electric Company Refrigerator Metering -- Part One. Energy Consumption Comparison, Proctor Engineering Group, CA September 1994.

Appendix A

Annotated Bibliography

This appendix includes references along with brief descriptions of recent professional literature in the general area of refrigerator replacements. Topics covered include technical, policy, programmatic, and evaluation.

"U.S. Residential Appliance Energy Efficiency: Present Status and Future Directions," by Isaac Turiel et al, *Proceedings of the ACEEE 1990 Summer Study on Energy Efficiency in Buildings.*[1] This is a classic article by ten researchers at the Lawrence Berkeley Laboratory which covers many subjects of relevance to energy-efficient refrigerators. The National Appliance Energy Conservation Act of 1987 established policy through which refrigerator standards were developed by the authors. These are expressed as annual electric energy consumption maximums in kWh as a function of adjusted volume, which is given by refrigerator volume plus 1.63 times freezer volume. The article notes that as of 1989, only seven of 2,114 refrigerator models then on the market met 1993 standards! Particularly fascinating is a plot of energy use versus adjusted volume of top mount auto-defrost refrigerator-freezers superimposed on curves showing both 1990 and 1993 standards. No machines on the list come close to meeting the 1993 standards. The article discusses a number of strategies for improving the energy performance of refrigerators, along with an analysis of the incremental cost and incremental benefit of each. The conclusion section of this important article includes the following observation: "Field use data are needed to adjust DOE test energy use data so that they more closely represent actual energy use in residences."

"Performance Tests of Compact Vacuum Insulation for Refrigerators," by T. F. Potter and D. K. Benson, *Proceedings of the ACEEE 1990 Summer Study on Energy Efficiency in Buildings.* Better insulation is a key factor in producing energy-efficient refrigerators, but manufacturers are loathe to give up food storage area per total volume. Accordingly, it is important to develop ways to achieve more insulating value per unit of wall thickness as cost-effectively as possible. This is a fascinating article on the development of compact vacuum insulation which can produce R-10 insulating values in a panel that is a tenth of an inch thick. Sundry technical problems and costs are discussed. The references at the end of this article lead interested readers to the patent and other literature on the issue.

"Analysis of 12 Japanese Refrigerators in the Northwest," by Peter Nelson and John Short, *Proceedings of the ACEEE 1990 Summer Study on Energy Efficiency in Buildings.* This article describes the results of short and long term testing of Japanese

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[1] Conference Proceedings and other publications by the American Council for an Energy-Efficient Economy are available through their publications office, 1001 Connecticut Avenue, NW, Suite 801, Washington, DC 20036 (202) 429-8873.

refrigerators in the field, using matched pair analysis. Owing to failure to measure indoor air temperatures at regular intervals and other variables out of control of the experiment, little of significance could be concluded other than that there was high variability in energy usage. Incidentally, since the DOE test is conducted at 90 degrees with no door openings, but the Japanese test is conducted at lower temperatures, but with door openings, the Japanese test predicts annual usages that are roughly 25 percent less.

"Efficient Refrigerators and Water Heaters: The Role of Third Party Buyers," by Lois Gorden and Linda Dethman, *Proceedings of the ACEEE 1990 Summer Study on Energy Efficiency in Buildings.* This article raises a key question: "Although refrigerators and water heaters account for up to 50 percent of the energy used in Northwest homes, highly efficient models of these appliances are rarely installed in new homes. Why, when the savings are very cost effective." The article explores a range of answers, many of which relate to the fact that people other than homeowners participate in the buying decision. This is especially the case in manufactured houses, of course, where builders indicate that least cost is the principal driving force in buying decisions. The solution in cases where homeowners are in the loop is to target influential groups, provide financial incentives, and provide good information.

"Beyond the Consumer: Leveraging a Refrigerator Rebate Program," by Dan Quigley and Bonnie Jacobson, *Proceedings of the ACEEE 1990 Summer Study on Energy Efficiency in Buildings.* This article summarizes the research of the Pacific Gas and Electric Company's refrigerator rebate program on the marketing decisions of manufacturers and retailers. The influence of this large utility on the marketplace was quite substantial, particularly in the early years, beginning in 1982. It concludes that it is important to accelerate efficiency improvements by better coordination with other utilities, which should influence manufacturers and retailers even more.

The Refrigerant Recovery Book, by D. Clodic and F. Sauer, 1992, available from the American Society of Heating, Refrigerating and Air-Conditioning Engineers, Inc. (ACEEE), 1791 Tullie Circle, N.E., Atlanta, GA 30329. An interesting text by French scientists that covers proven methods for the efficient and economical capture of CFCs from a wide variety of refrigeration systems. Includes quite detailed technical information and case studies.

"Vacuum Panel and Thick Insulation for Refrigerator/Freezers: Two Technologies that Work," by Alan Fine, Jean Lupinacci, and John Hoffman, *Proceedings of the ACEEE 1992 Summer Study on Energy Efficiency in Buildings.* This article is a nice study of the tradeoff of super insulation, cost, and marketability. Includes an interesting discussion of the use of focus groups in assessing consumer reactions to key energy and cost issues versus refrigerator volumes.

"Measured Electricity Savings of Refrigerator Replacement: Case Study and Analysis," by Danny Parker and Ted Stedman, *Proceedings of the ACEEE 1992 Summer Study* *on Energy Efficiency in Buildings.* An example of a very careful case study of the performance of single refrigerator as a function of many relevant variables. Kitchen temperature is the strongest predictor of energy performance. Inferences are drawn on both the energy and demand effects of refrigerator change out on the electric grid.

"Stalking the Golden Carrot: A Utility Consortium to Accelerate the Introduction of Super-Efficient, CFC-Free Refrigerators," by Michael L'Ecuyer, et al, *Proceedings of the ACEEE 1992 Summer Study on Energy Efficiency in Buildings.* This is a fascinating article about the origins of the Super Efficient Refrigerator Program and this unique effort to cause major manufacturers of refrigerators to produce more environmentally-friendly, energy-efficient units.

"Super Efficient Refrigerators: The Golden Carrot from Concept to Reality," by John Feist et al, *Proceedings of the ACEEE 1994 Summer Study on Energy Efficiency in Buildings* This article tries to tell the whole story of the SERP program, from environmental and energy policy through the development of analogous large-scale program opportunities.

"In-Home Metering of New Refrigerators," by Dan Quigley, William Miller, John Proctor, and Andy Goett, *Proceedings of the ACEEE 1992 Summer Study on Energy Efficiency in Buildings.* Results from monitoring refrigerators in PG&E program suggests that there are many anomalies with existing units in the field that cause undue consumption.

"The Effect of New Priorities and New Materials on Residential Refrigerator Design," by David Benson and Thomas Potter, *Proceedings of the ACEEE 1992 Summer Study on Energy Efficiency in Buildings.* This is a very useful article by researchers at the National Renewable Energy Laboratory about envelope measures in refrigerators. It is reproduced here both because it places this issue in the larger context of electricity use in this country and internationally, and because of its extensive bibliography.

"1991 and 1992 Trade-In Refrigerator Metering Project," by Willem Bos for the Sacramento Municipal Utility District, March 1993. Reports on test chamber testing of old refrigerators removed from households to evaluate the difference in performance with and without coil cleaning. Measured kWh savings were 2.95% per year with clean coils.

"Household Appliance Replacement Program--Impact and Tradeoffs," by Peter Benenson et al, *Proceedings of the ACEEE 1994 Summer Study on Energy Efficiency in Buildings.* This article describes the "Targeted Customer Appliance Program" conducted by the Pacific Gas and Electric Company. Its stated aim is to assist low-income customers to conserve their residential energy use. A key issue treated is how to compute energy-savings benefits when the customer's existing appliance is inoperative or non-existent, a circumstance which applied to the target population in the case of 26% of their refrigerators, 56% of their gas furnaces, and 24% of their gas water heaters! A distinction was drawn between those who would eventually purchase appliances versus those who would cope without them for the indeterminate future. It was concluded that energy-efficient appliances should be supplied in all cases, but that those in the latter class should not be included in an evaluation of a total program's energy savings impact.

"Estimating the Level of Free Riders in the Refrigerator Buy-Back Program," by Diane Fielding, *Proceedings of the ACEEE 1994 Summer Study on Energy Efficiency in Buildings.* This article describes a clever way of analyzing the issue of free riders in an impact evaluation of a refrigerator buy-back program in the service territory of B.C. Hydro. Through survey research and the use of probability theory, it produces what appear to be useful answers to the key question, "what would have happened in the absence of the program?" This article presents clear graphic analyses of the "destination" of primary and secondary refrigerators, and would be useful in planning expanded refrigerator replacement programs.

"Large Scale Residential Refrigerator Field Metering," by Gautam Dutt, John Proctor, Michael Blasnik, Andrew Goett, Elsia Galawish, and Dan Quigley, *Proceedings of the ACEEE 1994 Summer Study on Energy Efficiency in Buildings.* A comprehensive paper on the differences between measured and labeled performance on refrigerators. See below.

Pacific Gas and Electric Company Refrigerator Metering, Energy Consumption Comparison (Part 1) and Costing Period Study (Part 2), by John Proctor, Gautam Dutt, and Michael Blasnik, Proctor Engineering Group, 1994. A careful study reflecting field measurements of existing and new refrigerators in the field. Concludes that new refrigerators tend to perform 10 to 14 percent better than suggested by the DOE test (which is conducted at 90 degrees F). Suggests that consumer education should be directed to turn off the anti-sweat switch (which will save 100-125 kWh per year) and avoid use of the icemaker (thereby saving 75-105 kWh).

"Refrigerator Monitoring System Development and Field Testing Results," by Laurence Kinney and Michael Stiles. This paper presents the rationale for the need for special-purpose electronics for the monitoring of refrigerators and describes hardware and analytical software for measuring a range of performance characteristics of refrigerators in the field or in the laboratory. (This is the equipment that will be used in the present study; this article is reproduced in Appendix B.)

"Opportunities Found (and Taken): SMUD's Refrigerator Program," by Janis Erickson, *Proceedings of the ACEEE 1994 Summer Study on Energy Efficiency in Buildings.* A frank discussion of the problems tackled and solved by the program director of several utility refrigerator programs.

"The Chilling Truth about Appliance Recycling Programs," by Debra Steckel and Eric Heldebrandt, *Proceedings of the ACEEE 1994 Summer Study on Energy Efficiency in Buildings.* Suggests that energy savings are less than planned, so the most important benefits may lie in recycling. A large view of overall impact is key to program planning, execution, and evaluation.

"CFCs in Foam Insulation: The Recovery Experience," by Bruce Wall, *Proceedings of the ACEEE 1994 Summer Study on Energy Efficiency in Buildings.* The mechanics of the recovery process and results of large scale production processes for recovering CFC-11 from polyurethane foam insulation from appliances. The author suggests findings should affect national policy on disposing of urethane foam.

Appendix C

Client Brochure and Training Guide

What You Need To Do

- You will be notified when your new refrigerator will be installed. Please be available to open the door to your apartment on that date.
- Deliveries will be between 8 a.m. and 4 p.m. beginning with the top floors in your building. Please be patient in waiting for your delivery.
- Cooperate with our workers. The doors on your new refrigerator can be hinged on either side. If you have any questions, please notify the Housing Management Office.
- It will be easier to transfer food if you don't shop the night before you receive your new refrigerator.
- Enjoy your new, energy-efficient refrigerator!

Testing

The energy use of some old and some new refrigerators is being tested to measure savings. If your refrigerator is chosen for testing, please cooperate with the technicians.

Testing is being conducted by the Synertech Systems Corporation. If your refrigerator is selected, a representative of NYCHA or Synertech will call to arrange for a test. Electronic equipment will be installed temporarily to measure energy use. It will have no effect on the operation of your refrigerator.

Questions?

If you have any questions, please call the Management Office.

Thank you for participating in this important energy conservation project!

To NYCHA Residents– New Energy-Efficient Refrigerators Are on the Way!

Photo Credit Joseph Reyes Mayor's Press Office

Mayor Rudolph W. Giuliani looks on as NYCHA Chair Rubén Franco signs the refrigerator agreement. Standing, left to right are NYCHA Deputy Director of Research, William Steinmann, Board Member Kalman Finkel and General Manager Paul Graziano.

Important Information for Residents of NYCHA Buildings

Most older refrigerators waste a lot of electricity, and some require manual defrosting. New refrigerators are better insulated and temperature controlled than old refrigerators, and they contain only environmentally-friendly materials. They are also frost-free--no more defrosting! Best of all, they use much less electricity.

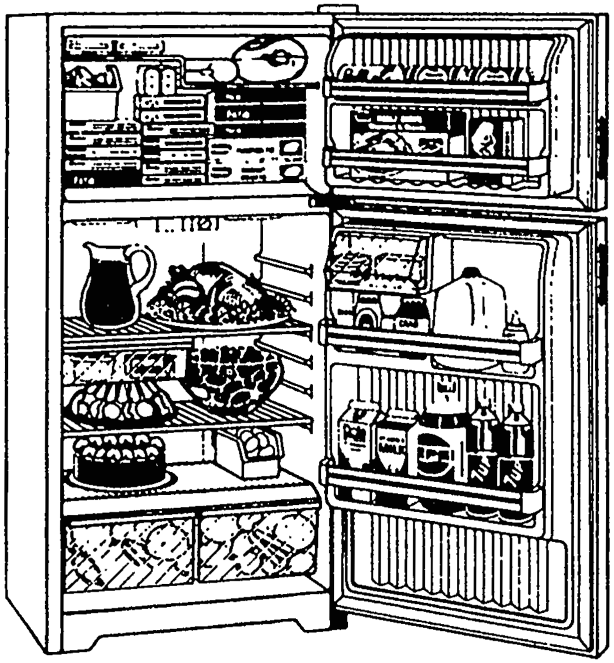
The New York City Housing Authority (NYCHA) is replacing inefficient, old refrigerators in their buildings with the best, most energy-efficient apartment-size refrigerators available. Eventually, 180,000 refrigerators will be replaced in New York City Housing Authority homes.

This brochure tells more about the program.

Residents Get Excellent New Refrigerators

Residents get excellent new refrigerators that are as large or larger than their old ones and are easier to maintain. This saves energy and improves the environment.

If the new refrigerator is too large for the space in your apartment, the Housing Authority will provide an energy efficient refrigerator that does fit.



Tips for Additional Savings

- ✔ **Leave temperature controls in mid-range or a bit warmer—so milk and ice cream taste "just right."**
- ✔ **Don't overload your new refrigerator with hot food.**
- ✔ **Don't leave the refrigerator door open for longer than you need to.**

Organizations Participating in the Program

The City of New York which, led by Mayor Rudolph W. Giuliani, worked to bring all of the agencies together to develop the program.

The New York Power Authority (NYPA), which supplies electricity to NYCHA's buildings, is providing the new refrigerators as well as low-interest financing, installation, and removal services for the refrigerator project. Saving electricity will help NYPA to delay building expensive new power plants. (NYPA is also helping to improve the efficiency of lighting, boilers, and elevator motors in NYCHA's buildings.)

The U.S. Department of Housing and Urban Development, which helps pay NYCHA's energy costs, will have a lower electricity bill when the new refrigerators are installed. These electricity savings will be used to pay back NYPA's investment in the new refrigerators.

The companies making the new refrigerators, like **General Electric** and **Maytag**, are assured of selling a large number of their products through this program. This will allow them to produce energy-efficient, environmentally-friendly refrigerators at lower costs for other apartment buildings throughout New York State and across the country.

Planergy, a recycling company hired by NYPA, is "demanufacturing" the old refrigerators. Possible pollutants are separated and dealt with in an environmentally-safe way. Metals are recovered for other uses.

The New York State Energy Research and Development Authority is sponsoring related research to measure how much energy is actually saved by the new refrigerators. The information is being used to study the costs and benefits of the program and to plan its next stages.

The U.S. Department of Energy is conducting laboratory tests and market research to speed the transition to energy-efficient refrigerators across the country. Through the Consortium for Energy Efficiency in Boston and other organizations, similar refrigerator replacement projects are being started in many states.

Synertech
Synertech Systems Corporation

SYN TN 96-525
June 1996

Training Guide

Refrigerator Testing and Analysis: A One-Day Training Session

Prepared as part of

Program Support and Evaluation

for the

New York City Housing Authority Refrigerator Replacement Program

Sponsored by

New York State Energy Research and Development Authority

Under Agreement

3015-EEED-BR-94

All users of this training guide are invited to comment on its substance and form. Please contact Dr. Laurence F. Kinney, Project Director, at the address and phone below or at the following E-mail address: lfkinney@mailbox.syr.edu

472 South Salina Street / Suite 110 / Syracuse, New York 13202-2401 / (315) 422-3828

Training Schedule

Thursday, June 13, 1996
New York Power Authority
1633 Broadway
New York, New York 10019

9:00 Introduction and overview

9:15 Review of principles of energy measurement and short-term analysis

9:45 W-100 and other field hardware, testing protocol, audit procedures

11:00 Site work (Amsterdam)

1:00 Lunch, review of site work

1:45 Data entry and analysis of W-100 data

2:30 Problems which can arise in the field and approaches to solving them

3:15 R-100 demonstration and discussion

4:00 Wrap up and evaluation

Objective

The objective of this training session is to equip attendees to understand both the philosophy and practice of accomplishing refrigerator testing in the field and conducting subsequent analyses.

Principles

The following is a general discussion of principles associated with measuring energy use of buildings or equipment. The principles express a philosophy that underlies both the NYPA/NYCHA refrigerator changeout program and this workshop.

Measuring consumption (or surrogates) helps in **defining** a conservation strategy as well as in **evaluating** its success. Ideally, this holds true not only in planning programs of whatever scale but also in deciding what to do with a specific building or even a system within a dwelling--a refrigerator or a distribution system, for example.

The Principle of Waste, the Principle of Focus and the Principle of Data Precision are critical to performing good quality, practical evaluation work--yet they are frequently ignored.

(1) **Savings follows Waste**. This is an empirical generalization in energy conservation programming that is virtually without exception. Put somewhat more elegantly, the savings resulting from energy conservation measures increase directly with before-retrofit consumption. It follows that quantifying waste is necessary in many (not all) circumstances to implement cost-effective conservation measures.

(2) The **Principle of Focus** may be stated quite simply: Decide as early in an evaluation project as possible what to measure--and what not to measure. Ignoring the Principle of Focus can result in an expensive fishing expedition in which massive data is collected without a clear sense of the use to which it will be put. Paying attention to the Principle of Focus forces early attention on a range of practical considerations. Evaluation techniques must reflect the context, both human and engineering, of the job. Is the job routine or one time only? Is it a program impact evaluation, or a quick estimate of current use so that an auditor can make an informed judgment about the cost effectiveness of various conservation options?

What are the stakes? Policy development for moving a program from demonstration to large-scale implementation? Quantifying payments for a performance contract? Measuring before-retrofit consumption to decide on the magnitude of a conservation investment likely to be cost effective? Measuring after-retrofit consumption to see if the investment decision was indeed wise? Adjusting techniques for more efficient future auditing? Adjusting tactics for installing equipment? Testing a sample of retrofit jobs to assess quality control of the equipment or installation technique? Identifying appropriate applications for different equipment? Checking for interactions among measures? Determining the persistence of savings over time? Gathering management information for an ongoing program (with a view to making mid-course corrections)?

Getting focused on the agenda(s) makes the planning and execution of an of a conservation program evaluation more cost effective. Sometimes it is useful to produce tables of dummy results before data gathering begins to be sure that data gathered nicely matches needs.

(3) The **Principle of Data Precision** is similarly pragmatic, for it reminds us to think systematically about the ends of an evaluation. When several numbers must be multiplied by each other to yield information of value in decision making--and one number cannot be quantified more accurately than plus or minus 10 percent--there is little use in trying for three decimal place precision on the second number unless it is useful for an unrelated purpose.

What we seek are practical, clever, cost-effective techniques for measuring what we really care about as carefully as possible followed by analysis that respects these three principles (and others...)

Notes on Short-Term Testing

What we seek are practical, clever, inexpensive techniques for measuring what we really care about as carefully as possible followed by analysis that respects the three principles described above.

Many phenomena lend themselves to short-term analysis.

Consider savings associated with an engine rebuild. The appropriate strategy may be to use a dynamometer before and after the rebuild job to quantify savings. Alternatively, 30 miles of mixed city/highway road with micro-metered gas consumption is likely to be superior to longer-term measurement with poor controls where many other variables may affect measurements. The trick is to vector in on the information we really want--and use simple, inexpensive techniques to obtain it.

Analogous remarks apply to energy consumption in many sectors.

Consider, for example, the water bed.

Demand (Kw) may be measured with simple volt meters and ammeters one time, then the water bed can be equipped with an elapsed timer that counts time when the water bed thermostat calls for heat. This allows for the direct measurement of duty cycle. Tracking the difference in temperature between the water bed and the surrounding environment allows for obtaining an index of consumption such as watt hours per day per delta T. Then one may undertake various retrofit measures. Let us imagine that one insulates (e.g. surrounds five of six sides with high-R sheathing), lowers the thermostat, and installs a timer that turns off the heater during evening hours (which addresses health-related electromagnetic field [EMF] problems as well as conservation issues). Then, metering again for several days, to first order, percentage savings is proportional to the change in duty cycle. Estimating indoor air temperature throughout the year allows for computing normalized annual consumption before and after retrofit, and whence both absolute and percentage savings.

It may also be interesting to measure the time constant with and without insulation. Just as in the electronic case, the time constant t = RC, where t is time in hours, R is the overall effective R-value of the water bed and C is the thermal capacitance of the system. C can be assumed to be a constant. (This isn't quite right if one adds insulation and effectively "redefines the envelope" because before retrofit the envelope includes at least a portion of the water bed frame; afterward, little or none. Nonetheless, with a king-size water bed weighing about 1450 pounds, the portion of the frame constituting part of the C is less then 3 percent.) The effective R value of the system can be determined by measuring t and dividing by C. Before and after retrofit R can be thus determined. Then a simple Q = 1/R x A x delta T analysis can be accomplished, checked against actual Q using elapsed timer method, then used for other delta T's over the year to predict a cumulative annual use before and after insulation. The relative noise and uncertainty associated with each approach should be studied carefully, of course, particularly in application to other energy systems we care more about.

Interestingly, short-term measurements of major energy conservation retrofits of houses is also feasible and even desirable under many circumstances.[1]

The Case of Refrigerators

Importantly, refrigerators also lend themselves to a similar kind of analysis. However, since a portion of the load is reactive (owing to the compressor motor) one needs a kWh meter (unless the machine is a manual defrost model) instead of an elapsed timer to estimate energy use. Drift tests--accomplished by unplugging the refrigerator and noting the rate of temperature increase in an environment of constant temperature--with and without a known mass within the refrigerator allow for writing simultaneous equations through which the overall R-value of a refrigerator may be determined. This procedure is

[1] For example, see L. Kinney, "A Cost Effective Technique for Determining By-Measure Conservation Savings: Several Cold Nights May be Enough," paper presented at the Third International Conference on Energy Conservation Program Evaluation, August 1987.

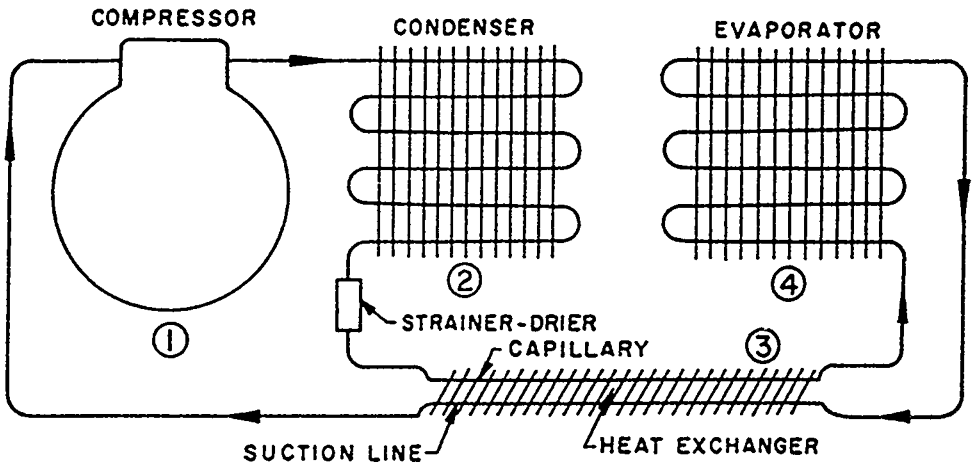
discussed toward the end of the paper reproduced in Appendix B. Of course, for routine auditing, this isn't necessary.

As shown in the block diagram on the following page, in principle, refrigerators are not very complicated devices. Work, produced by an electric motor drives a compressor. The motor-compressor is typically a single, sealed unit to prevent the escape of refrigerant gas. The unit compresses the refrigerant gas, producing a high-pressure vapor. It is then converted to a liquid in the condenser, which releases heat outside of the insulated refrigerator box. The liquid, still under high pressure, goes through an expansion valve which lowers the pressure on the liquid, resulting in a lower-pressure mixture of liquid and vapor. This mixture enters the evaporator in the freezer, where it removes heat and is converted to a gas. The resulting low-pressure vapor is drawn into the compressor and process continues.

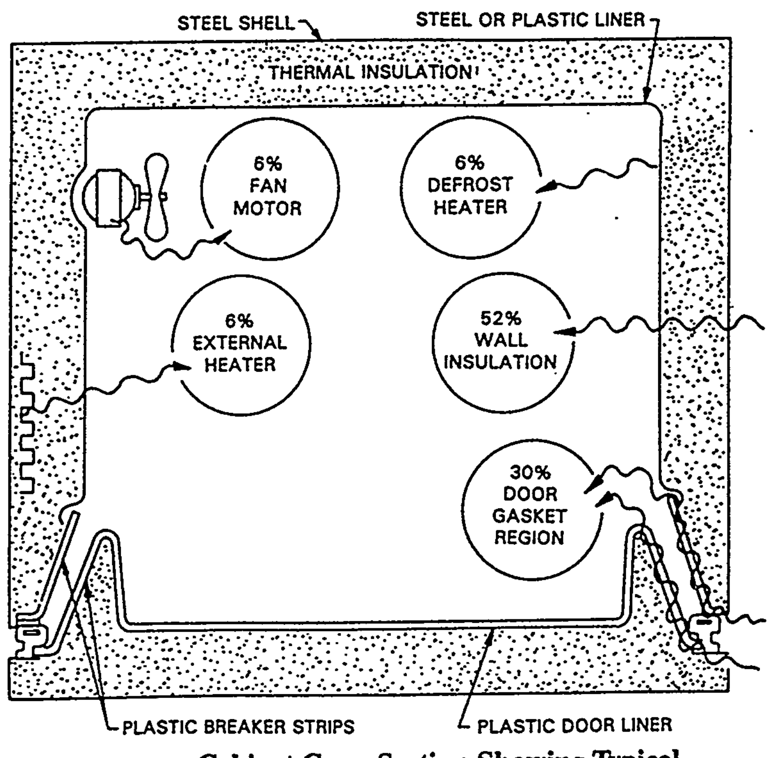
To be sure, refrigerators are more than an insulated box with a cooling system; they are surprisingly complicated devices. In addition to a heat pump with a compressor which uses energy, there are systems with fans and dampers to move and control cold air and as many as six electric resistance heaters, from light bulbs and anti-sweat heaters to defroster coils. Defrosters typically draw 400 watts or more and can dramatically raise the temperature in the freezer during defroster-run periods. These typically occur at the end of 12 hours or so of compressor run time and last for 10 to 14 minutes. However, during the defrost cycle, freezer temperatures can be well above freezing for more than 30 minutes.

The attached diagram shows some typical sources of losses, according to the most current addition of the *ASHRAE Handbook on Refrigeration Systems and Applications*. (1994). (Chapter 48, "Household Refrigerators and Freezers," is reproduced here as Appendix A.)

In light of the fact that in 1990 only a handful of the thousands of models of refrigerators then existing met 1993 standards (the "fleet" mileage was then probably around 1300 kWh/year), it is instructive to examine these losses. As a group exercise, we should speculate (1) whether they apply to newer, more energy efficient refrigerators, and (2) what opportunities still exist for reducing energy losses.



Refrigeration Circuit



Cabinet Cross Section Showing Typical Contributions to Total Heat Load

The Present Case

The plan produced for this project covers most of the important considerations outlined generally above.[2]

The fundamental objective of the analysis is to develop accurate, defensible average annual savings estimates for the high-efficiency replacement refrigerators relative to the existing models replaced, bounded by known and reasonable levels of uncertainty.

By necessity, we must infer long-term performance from short-term testing. Hence, we must:

- Adjust the short-term data for the pattern of indoor temperatures experienced over the year;
- Develop average savings estimates for each model replaced;
- Account for the persistence of savings over time;
- Account for heating and cooling interactions, if any; and
- Verify that the replacement refrigerators perform as specified by the manufacturer.

The three-pronged testing described in the Plan envisions testing with the R-100, an 11-channel data logger, (1) in the field and (2) in Synertech's test chamber. Most important, it envisions extensive testing using the W-120 watt hour meter.

Items for Discussion

You may refer to the Plan, Synertech's handout from yesterday's meeting, or any other material in discussing the following questions:

Examine page one of the audit form reproduced on the following page. What is the usefulness (or potential usefulness) of each piece of information?

Examine page two. Note that the procedure for calculating the material on each line is shown. Please perform the calculations using a hand calculator. Do these calculations make sense? Do the four indices of performance make sense? For what purposes are they useful? What errors are involved in trying to estimate annual performance from short-term performance? What are the optimal lengths of testing periods? Are there other indices of performance that may be useful in evaluating refrigerator performance? What is the effect of ambient temperature on refrigerator performance? What is the effect of control setting on refrigerator performance? What other effects are important?

[2] *Evaluation Plan for the New York Power Authority/New York City Housing Authority Refrigerator Replacement Program*, Syn TD 95-554, ver 1.3, June 1996.

Refrigerator Audit Form - NYCHA

Synertech Systems Corporation

Audit Date: 1/26/96 | Site Location: Edenwald | Sequence: 94F1165pt

Customer Information

Customer: Emily Crooks | Phone: (718) 798-6253 | Occupants:

Address: 1165 E 229 St apt 4F | City/St/Zip: Bronx

Refrigerator Information

Style: top freezer

\# doors: 2 | Defrost: Automatic

Mfr: Hotpoint

Model: CTH14CYXLLWH

Year Mfd: 1995 | Est?: No

	Height	Width	Depth	
Outside:	61.25	28.25	27	in.
Refrig:	37	25	22	in.
Freezer:	15	23.5	18.5	in.

Food Load: 50 % of Refrig

Food Load: 70 % of Freezer

Frost: 0 in., max accum.

Anti-sweat switch in position using electricity?: Yes

Refrig Control: 5 on scale of 9

Freezer Control: N/A on scale of

Consumption Data

Logger Model: R-100 | S/N: 004

	Start	Stop
Date and Time:	2/2/96 11:00:00 AM	2/8/96 10:30:00 AM
Logger Record No.:	0	0
Compressor On?:		
Ambient Temp, deg F:	75.9	76.9
Behind Temp, deg F:	71.4	74.3
Refrig Temp, deg F:	41.7	43.8
Freezer Temp, deg F:	17.9	14.4

Measured Consumption: 5807 Wh

Est. Average Annual Temp: 0 deg F

Utility: NYPA

Rate: $0.00 per kWh

Notes:

Calculate <<< Push this button to derived values which follow...

Parameter	Value	Units	Derivation
Mean temperature, ambient:	0	deg F	(ambient temp start + stop) / 2
" behind:	0	deg F	(behind temp start + stop) / 2
" refrigerator:	0	deg F	(refrig temp start + stop) / 2
" freezer:	0	deg F	(freezer temp start + stop) / 2
Volume, outside:	0.0	cu. ft.	outside height * width * depth
" refrig:	0.0	cu. ft.	refrig height * width * depth
" freezer:	0.0	cu. ft.	freezer height * width * depth
Interior volume:	0.0	cu. ft.	refrig volume + freezer volume
Adjusted interior volume:	0.0	cu. ft.	refrig volume + 1.63 * freezer volume
Elapsed Time:	0.0	hours	logger stop time - logger start time
Raw energy use per hour:		Wh	measured watt hours / elapsed time
per day:		Wh	24 * raw energy use per hour
Net interior temperature:	0	deg F	(ref temp*vol) + (frz temp*vol) / (int vol)
Temperature difference:		deg F	annual ambient - net interior temp
Correction factor:		%	2% * temperature difference
Adjusted energy use per hour:		Wh	raw use per hour * (1 + CorrFact/100)
per day:		Wh	24 * adjusted use per hour
per year:		kWh	365 * adjusted use per day
Figure of Merit "T":		Wh/day/deg F	Adj. use per day / net interior temp
" "V":		Wh/day/cu.ft	Adj. use day / adj. volume
" "TV":		Wh/day/F/cu.ft	Adj. use day / net interior temp / adj. vol
Est. annual operating cost:			Electric rate * Adj. energy use per year

Tools Useful in Field Monitoring

(R-100 Refrigerator Monitor
w/three temperature-door
opening sensors)
(Portable computer)

W-120 Watt-Hour Meters
Magnet
Infrared scanner
Digital thermometer
Electrical tester
Extension cord
Electrical outlet adapter
Calculator
Wrist watch
Tape measure
Camera, film, batteries

ID Tag
Project Brochure
Names and addresses
Refrigerator Audit Form
Red marking pen (or tape)
Routing labels
Duct tape
Electrical tape
Velcro
Paper towels
Vinegar
Pliers
Flashlight
Screwdriver
Wire staple
Container for carrying equipment
(Luggage cart)

Appendix D

Temperature Data Corrections

Appendix D

TEMPERATURE DATA CORRECTIONS

A series of comparative measurements using both an infrared scanner and a thermocouple were made in the freezer and refrigerator compartments of a set of installed refrigerators. The infrared scanner was an Exergen microscanner model D501. It was set to record the minimum temperature during a scan and hold that value in memory. The scanner was then directed to take readings from all exposed surfaces in the compartment. The lowest value was then recorded.

The thermocouple measurements were made with a small thermocouple wire having a time constant of several seconds (with Fluke #52 meter). The compartment door was opened and closed quickly to enclose the thermocouple in the chamber for 5 minutes (or until steady-state was reached). A reading was then recorded.

A comparison of the two sets of measurements is plotted in Figure D-1. The optical sensor shows good agreement with the thermocouple in the refrigerator compartment but significantly higher (than the thermocouple) readings in the freezer. This may result from a partial fogging of the freezer air and a corresponding impact on the scanned measurement. Better correlation might be achieved in future measurements if the scanner is placed in contact with an exposed surface as opposed to leaving separation. Also it is known that the infrared scanner is biased by differences between the ambient temperature (that the scanner electronics have come to equilibrium in) and the surface temperature that it is measuring.

The points in Figure D-1 are regressed to form a linear correction relationship for scanned measurement. However, due to logistical limitations in the collection of the site temperature measurements (refrigerator, freezer and ambient), it was not considered appropriate to apply this relationship. All temperature measurements are left as recorded in the field.

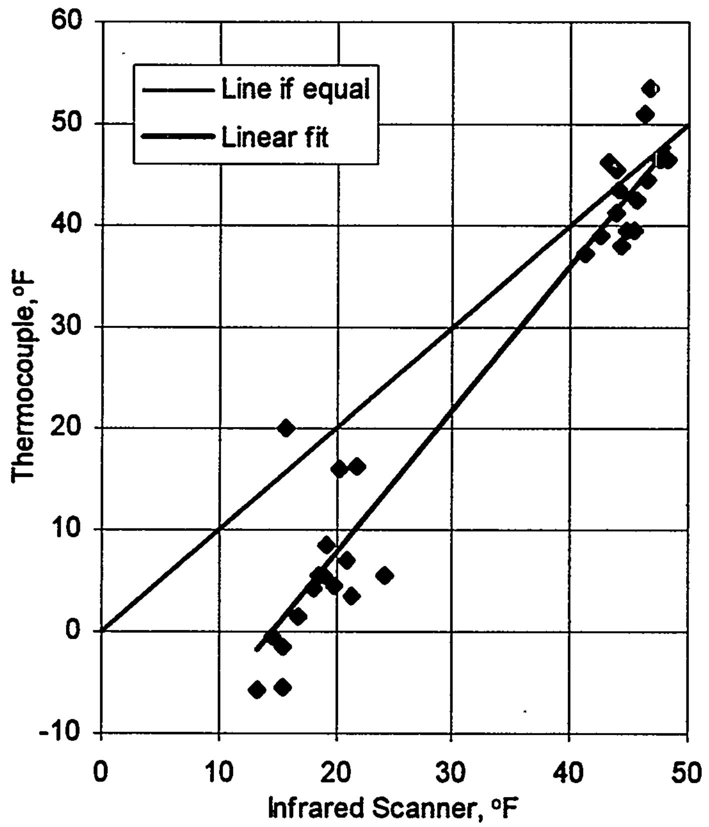


Figure D-1. Comparison of Infrared Scanner and Thermocouple Sensor Measurements

Appendix E

Temperature Difference Adjustments to Annual and Population-Average Conditions

Appendix E

TEMPERATURE DIFFERENCE ADJUSTMENTS TO ANNUAL- AND POPULATION-AVERAGE CONDITIONS

The impact of temperature on consumption can be broken into two components: conduction loads through the refrigerator envelope and cool-down loads. Cool-down loads result from cooling food and air associated with door openings (occupant interactions). Both of these components increase with increasing ambient temperature. The efficiency with which the unit satisfies the conduction load depends on the thermal resistance in the unit's shell and also the COP of the compressor. The cool-down load is addressed mainly by the compressor. One approach to consumption correction is to analyze the two components separately.

CONDUCTION (NON-LINEAR) CORRECTION

The change in conduction loads associated with a change in operating temperatures can be estimated from DOE-label type chamber testing (no door openings). As shown in Figure E-1, chamber data on the new units can be taken over a range of operating conditions and then used to form a non-linear relationship between annualized consumption and ΔT -- the difference between ambient (chamber) and the internal (compartment-surface-area weighted temperature).

Each point in Figure E-1 represents a consumption test at controlled ambient conditions. Consumption is recorded between the end of one defrost cycle and the end of the next[1]. The consumption total during this test is then annualized based on the runtime. Testing at lower ΔT reduces conduction loads and corresponding consumption.

[1] Refrigerator defrost events are triggered by a timer. The timer initiates a defrost cycle when the compressor runtime exceeds a set amount.

The curve in Figure E-1 represents the total response in annualized consumption due to changes in loading, COP, and associated defrost energy as effected by ΔT. Consumption approaches zero as ΔT approaches zero. This is equivalent to saying that, as room temperature approaches the set-point temperature in the refrigerator compartment, the conduction load approaches zero. This is because freezer compartment temperatures are not thermostatically controlled, but instead float in response to cooling done to maintain a set-point in the refrigerator compartment. As the load on refrigerator compartment approaches zero, the temperature in the freezer compartment approaches that of the refrigerator. The curvature in the plot is believed to be partially the result of non-linear COP behavior of the compressor.

The change in conduction-related energy consumption is estimated as the change in this curve between two ΔT points (Equation E-1).

$$\Delta E_{conduction_{NEW}} = F(\Delta T_{target}) - F(\Delta T_{actual}) \qquad \text{(E-1)}$$

where: $\Delta E_{conduction\_NEW}$ = temperature based correction to annual conduction loads, kWh/yr

F = regression function relating annualized consumption and ΔT

ΔT_{target} = target differential between ambient and internal temperature, °F

ΔTactual = actual differential between ambient and internal temperature, °F

If it is assumed that the general shape of the curve is similar for all refrigerators, the function F can be generalized for use with the existing units through use of a label based correction factor (Equation E-2).

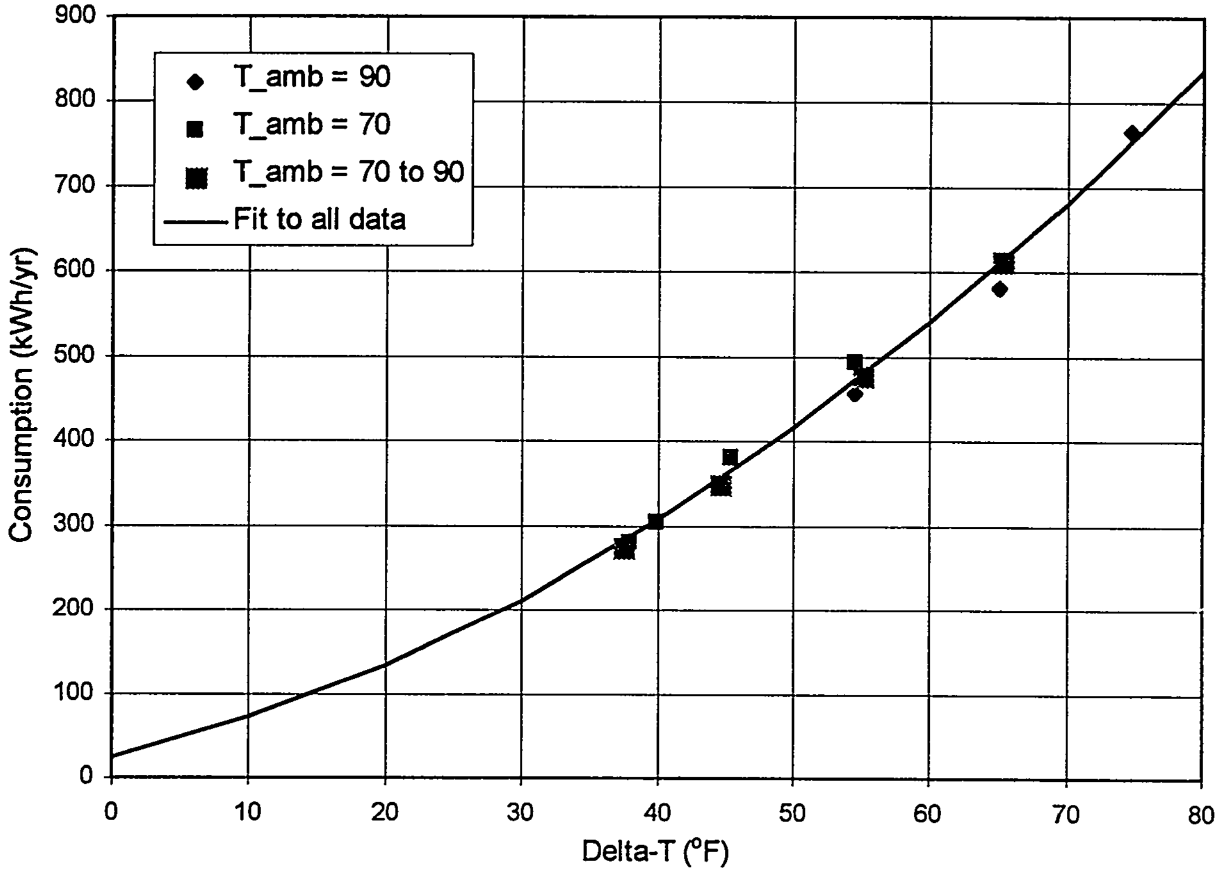


Figure E-1. Relationship of Annualized Consumption and Temperature Difference

$$\Delta E_{conduction\ OLD} = \left(\frac{L_{old}}{L_{new}}\right)\left(F(\Delta T_{target}) - F(\Delta T_{actual})\right) \qquad \text{(E-2)}$$

where: $\Delta E_{conduction\ OLD}$ = correction to conduction loads for existing refrigerators, kWh/yr

L_{old} = label rating of a particular existing refrigerator, kWh/yr

L_{new} = label rating of the new refrigerator, kWh/yr

Corrections to the cool-down component of consumption are more difficult to estimate, mainly because it is not possible to determine the relative contribution from cool-down and conduction in a simple monitored energy total. The primary data loggers used (Synertech W-100) sampled energy usage and record only the total energy. Therefore the program's sample of gross energy consumption can not be directly corrected for cool-down effects.

Even with more detailed data (such as that from the 15-minute data loggers, Synertech's R-100) there remains an obstacle to making temperature corrections on the cool-down component. Information on compressor COP (as a function of internal and ambient temperature) is needed.

To circumvent the difficulties in projecting the cool-down component it can be assumed that corrections to the cool-down component are, on average, equivalent for both the new and existing units. The impact of this assumption is that when calculating differential consumption (savings), the temperature corrections to the occupancy effects drop out of the analysis. Therefore corrections to savings estimates can be based strictly on corrections to the conduction component.

This simplifying assumption depends on three underlying assumptions: (1) the COP characteristics of the new and existing units are equal, (2) on average the occupant behavior generating the cool-down loads is equal for both the new and existing refrigerators, and (3) when projecting to a common temperature, any differences between the original sample-average temperature of the new and existing units is small,

The final annual consumption result is calculated as:

$$E_{corrected} = E_{raw} + \Delta E_{conduction} + \Delta E_{cooldown} \quad \text{(E-3)}$$

where Equation 0.2 is used for existing units. It must be emphasized that any corrected energy consumption, calculated with a conduction correction, does not include the

$\Delta E_{cooldown}$ correction. It is not available for calculation (as explained above, the cooldown fraction and COP data are not available) and therefore it can not be included. These corrected results are not to be used as absolutes but only as input to savings calculations.

If the simplifying assumptions above are incorporated, the cool-down component is eliminated in savings calculations:

$$\begin{aligned} E_{savings} &= E_{corrected\_old} - E_{corrected\_new} \\ &= (E_{raw\_old} - E_{raw\_new}) + (\Delta E_{conduction\_old} - \Delta E_{conduction\_new}) \end{aligned} \tag{E-4}$$

PURE ΔT (LINEAR) CORRECTION

Lacking detailed information on cool-down fraction and refrigerator COP characteristics, there is an alternate simplified approach to temperature correction. This is done by keeping the two load components together and making an approximation that total consumption is proportional to ΔT.

Each observed field consumption can be projected to a new ΔT as shown in Equation E-5. If the ΔT increases by 25% the projected consumption increases by the same 25%.

$$E_2 = E_1\left(\frac{T_{a\_2} - T_{i\_2}}{T_{a\_1} - T_{i\_1}}\right) \tag{E-5}$$

This approximation asserts that, for a given fractional increase in ΔT, both the energy consumption associated with the conduction component (compressor and related defrost energy) and the energy consumption associated with the cool-down component (compressor and related defrost energy) will have the same fractional increase. Underlying this assertion is the assumption that, similar to the conduction component, the cool-down component approaches zero as ΔT approaches zero. This is equivalent to stating that the majority of warm food placed into the refrigerator is at a temperature near ambient (hot food is generally left to cool first before storing in the refrigerator; food recently purchased at the store will either be at room temperature or near refrigerator or freezer temperatures; warm air entering the refrigerator will by definition be at ambient temperature).

Also it assumes that non-linear variations in consumption, mainly relating to COP, are not significant. Support for this assumption can be found in Figure E-1, where it can be seen that the conduction related consumption is strongly correlated with ΔT and that variation in COP (with changing ambient or internal temperature) is responsible for only slight curvature in the plot over the range of interest.

This approach is especially compelling because it greatly reduces the requirements for data and the complexity of the analysis:

- No estimates are needed for the cool-down component. Both components are corrected in the same simplified (proportional to ΔT) approach. There is no need to separate them.
- No label rating is needed. This projection method works equally well for new and existing units.
- No chamber testing results are used.
- No detailed metering of power consumption is used.
- No COP data are used.
- This approach can be used in producing absolution consumption numbers for both the new and existing units. This is unlike the conduction-correction method which is limited to producing input for savings calculations (difference between new and existing units).

It should be noted that this simplified linear analysis can be used in calculating savings and compliments the non-linear methodology. Both the linear and the conduction-correction methods are to some degree limited by assumptions; however, the two approaches produce nearly identical savings results in this analysis. When looking at absolute consumption, the linear approximation is preferred because corrections to the cool-down effects are automatically included in the accounting.

PROJECTION TO OTHER SITES

While the linear ΔT approach is compelling for analysis in the NYC study, it is fundamentally limited when projecting to other locations. This is because projecting to a different location involves not only projecting to different operating temperatures but also possibly a different culture and strongly different door-opening behaviors. In terms of equations presented above, a different culture may have a different X_{cd} (cool-down fraction of total consumption). The ΔT approach is only valid if this fraction is on average equal for the sample and the population that it represents. This is simply because the conduction and cool-down components are not separated in the analysis.

The conduction-correction approach outlined above could in principle be extended to accommodate a different X_{cd} at the projected site. The conduction term can be projected based on the operating temperatures. The cool-down term would be estimated at the new site based on some site/culture-specific sample of door-opening behavior and a site-independent relationship between consumption and door-opening events.

ESTIMATE OF ANNUAL AVERAGE AMBIENT TEMPERATURE

The temperature correction methods are implemented in the NYC study through the determination of target temperatures to which the field results are projected. In the analysis tool, target internal temperature can either be set to a user-determined value including the average of the field sample, or left as the actual measured internal temperatures. This feature, for example, can be used to test the sensitivity to changes in refrigerator control settings. Unless specified differently, for all the results reported, the internal target is set to equal the average of the field sample. This reflects the fact that internal temperatures are not strongly affected by changes in seasons and associated changes in the room temperature.

Appendix F

Demand Impact Estimation

Appendix F

DEMAND IMPACT ESTIMATION

Coincident-demand charges for the refrigerators in this program are calculated based on their contribution to the building load at the time of building-peak power usage. Estimates of coincident demand charges are calculated as shown in Equation F-1.

$$D = P_{average} F_{peak/average}(t_{coincident}) R \bullet 12/1000 \quad \text{(F-1)}$$

where: D = Annual coincident demand charge.

$P_{average}$ = Total-average power draw (for each model), W

$F_{peak/average}$ = Ratio of hourly-average to total-average (by time of day)

$t_{coincident}$ = Time of day for building peak (coincidence information)

R = Demand rate, \$/kW-month

$P_{average}$ is based on gross power-usage records (either metered or modeled) for each model of refrigerator and is simply the annual load estimate divided by the number of hours in a year.

$$P_{average} = \frac{E_{annual}}{8760}$$

where: E_{annual} = Annualized energy consumption (kWh/yr)

The $F_{peak/average}$ is determined from detailed field monitoring on 17 refrigerators (each logged at 15-minute intervals for 6 or more days). A plot of $F_{peak/average}$ is shown in Figure 5-5 in Section 5 of the main body of this report) as function of time of day. Each point on this plot is determined by the average consumption for a specific hour divided by the average consumption for all 24 hours.

In order to remove cycling variations (and anomalous contribution to the load shape), the individual time series are first smoothed. This is done by substituting the average values resulting from a moving 75-minute[1] window.

Then each of the 17 time series is averaged by hour of day. These 17 load shapes are then given equal weight in determining the overall average load shape shown in Figure 5-5. This averaging of the averages is necessary to avoid giving higher weight to the apartments with longer monitoring periods (some were monitored for approximately two weeks).

Also shown in Figure 5-5 is the average that results if no pre-smoothing is done (Trace labeled "Raw"). The difference between the pre-smoothed and raw traces is due to the small sample size. As metering increases beyond 17 units, cycling variation will naturally be removed in the time-of-day averaging process, and the "raw" sample averages will approach the "pre-smoothed" result.

The 17 refrigerators were monitored over a period of time ranging from January to September. If the results are separated by season, winter (with start dates ranging from 1/5 to 2/17) and summer (start dates ranging from 5/23 to 9/12), the load shapes appearing in Figure F-1 result (both traces have pre-smoothed data).

[1] The duration of the moving-average window is 75 minutes for the majority of the 17 units processed. Longer windows (up to a maximum of 4 hours) were used for those refrigerators with long cycle periods.

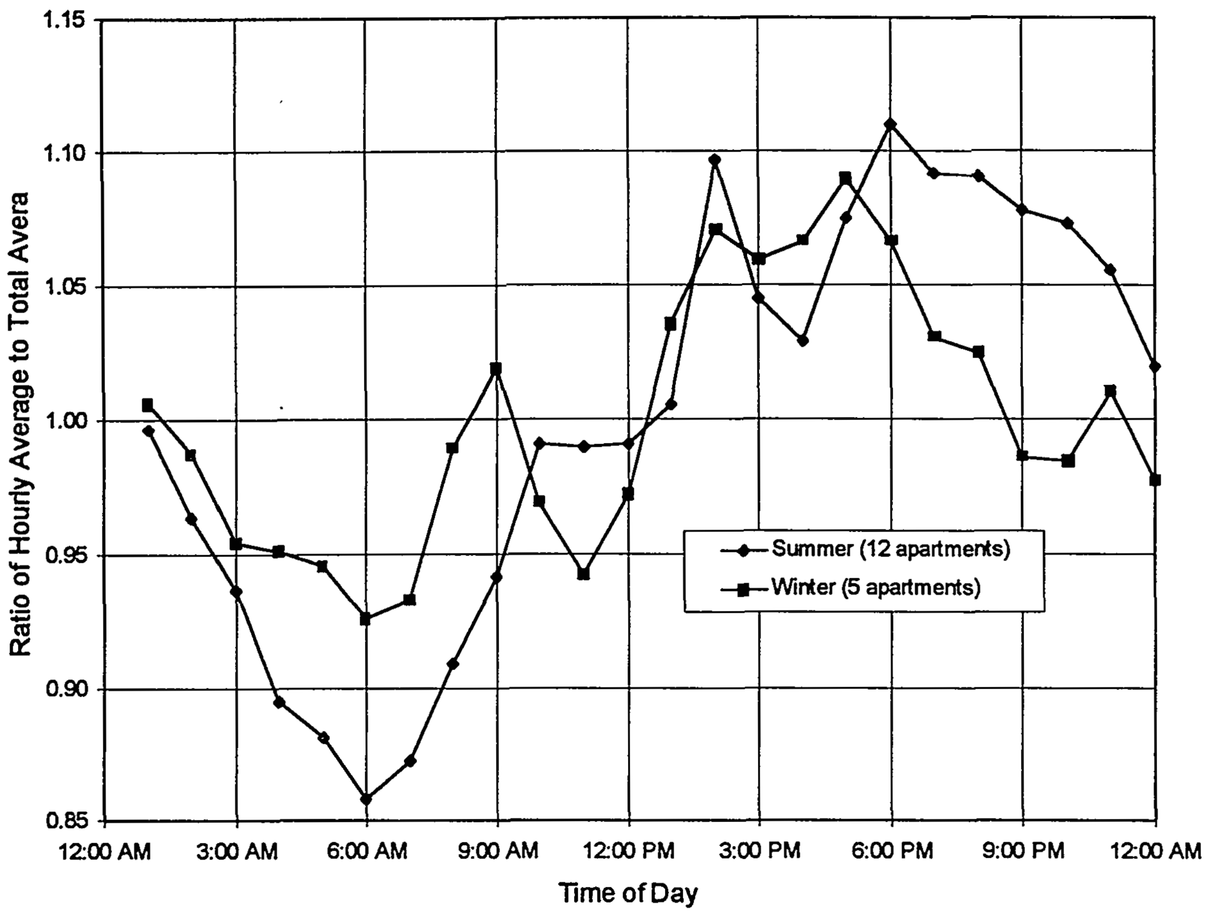


Figure F-1. Load Shape by Seasons

$F_{peak/average}(t_{coincident})$ is then determined as the value of $F_{peak/average}$ at the time of building peak consumption. This can be done for both summer and winter period using the average of building peak-time data from ten buildings. However, due to the small amount of detailed metering done during the winter season, the lumped load shape (in Section 4.5 of the main body of this report) is used for both the summer and winter seasons. The result is shown in Table F-1 with a summer coincident-peak-to-mean ratio of 1.050 and a winter coincident-peak-to-mean ratio of 1.078. The average of these two values, 1.064, is used to represent the whole year.

Table F-1. Summer/Winter Building Peaks and Coincident Peak-to-Average Refrigerator Ratios

Complex	Summer Peak	Winter Peak
Jackson	9:15 PM	6:15 PM
Rutgers	8:15 PM	6:30 PM
Morris	9:00 PM	8:00 PM
Pink	8:45 PM	5:30 PM
Bronx River	9:45 PM	6:45 PM
Isaacs	8:30 PM	6:45 PM
Butler	9:15 PM	7:15 PM
Mitchell	9:15 PM	7:30 PM
Barach #18	8:00 PM	6:45 PM
Adams	9:45 PM	6:45 PM
Average	8:58 PM	6:48 PM
Coincident	1.050	1.078

Appendix G

Confidence Interval Estimation

Appendix G

CONFIDENCE INTERVAL ESTIMATION

Confidence intervals for the estimate of savings can be determined through a stratified analysis of sample mean and variance (Cochran 1980). Strata mean and variance are weighted by records of strata population to produce estimates of the mean consumption and the corresponding variance for the existing units. This is also done for the single-stratum population of new units. Together, they combine to produce an estimate of program savings and a confidence interval.

MEAN VALUES

The estimate of the mean for the population of **new** refrigerators is simply the average of the sample of n new refrigerators.

$$\overline{E}_{replacement} = \frac{1}{n}\sum_{k=1}^{n} E_k$$

The estimate of the mean energy consumption of the population of **existing** refrigerators is the total of all contributions to the mean from each stratum as weighted by population fraction[1]. A mean, $\overline{E}_i$, is determined for each stratum using the consumption model. These means are then weighted by the corresponding population fraction and then summed.

$$\overline{E}_{existing} = \sum_i W_i \overline{E}_i$$

where the weighting factor W_i is the fraction of the total population in stratum i,

$$W_i = N_i / N$$

[1] These (strata) calculations produce mean values equivalent to those presented in Section E-6.

SAVINGS AND CONFIDENCE INTERVALS

The estimate of savings and the corresponding confidence interval are calculated as shown. The savings are simply the difference between the estimated mean of the existing and new units. The standard error of the savings is calculated as the root of the sum of the squares of standard error for the existing and new units. The confidence interval is then the product of the savings standard error and the Student's t factor for n_{df} degrees of freedom[2].

$$E_{savings} = \overline{E}_{existing} - \overline{E}_{replacement} \pm \left(\sqrt{s^2(\overline{E}_{existing}) + s^2(\overline{E}_{replacement})}\right) \bullet t_{st}(n_{df\_savings})$$

$$\text{where: } t_{st} = \text{t values from Student's distribution for n degrees of freedom}$$

The estimate of the standard error for the population of existing units is taken as the population-weighted sum of contributions to standard error by each stratum (Equation G-1). Here the standard error from each sampled stratum is weighted by the population fraction, squared, summed over all strata, and then the square root is taken.

$$s(\overline{E}_{existing}) = \sqrt{\sum_i W_i^2 \frac{s_i^2}{n_i}} \qquad \text{(G-1)}$$

where:

$s(\overline{E}_{existing})$ = standard deviation of the mean of $E_{existing}$ (i.e., standard error)

$\sqrt{s_i^2 / n_i}$ = standard error of sample in stratum i

s_i = standard deviation of sample in stratum i.

Equation G-1 is also be applied to the single stratum for the new units (only one type of new model at this point in the project). For a single stratum, it reduces to the usual expression for standard error (standard deviation over the square root of n).

An estimate of the standard error for each existing-unit strata is made through use of the consumption model and the strata label rating (Neter 1974).

[2] In this study the final sample of existing units was sufficiently large such that t values can be replaced with z values from a table of normal distribution. For example, the normal z value for 95% confidence is 1.96 and for 90% 1.64.

$$s(\hat{Y}_i) = \sqrt{MSE\left[\frac{1}{n} + \frac{(X_i - \overline{X})^2}{\sum_j (X_j - \overline{X})^2}\right]} \quad \text{(G-2)}$$

where:

$s(\hat{Y}_i)$ = Estimated standard error for stratum i

$\hat{Y}_i$ = Estimated mean value for stratum i

$$MSE = \frac{\sum_j (Y_j - b_0 - b_1 X_j)^2}{n-2}$$

X_i = Label rating in stratum i

$\overline{X}$ = Average label rating of the sample of existing refrigerators

X_j = Label rating of observation j in the sample of existing refrigerators

n = Number of observations in the sample of existing refrigerators

POPULATION-WEIGHTED RESULTS

Table G-1 presents the results of the population weighted calculations.[3] The actual stratum count is shown in the column labeled "Population," the population-weighted mean is shown in the top two rows of the column labeled "Corrected Energy," and the population weighted standard-error is shown in the column labeled "StdErr^2." The algorithms for determining these results are described in the preceding two sections.

The first row, below the New and Existing summary rows, represents all of the population that does not fall into metered strata (5892 units). Essentially, this is a lumped stratum composed of many different strata as defined in Appendix H. This row is processed differently than the rows below it because it is composed of units of different label ratings and because of the non-linear nature of the calculation for stratum standard error (Equation G-2). Because of this, Equation G-2 is actually applied to each un-metered stratum and weighted as shown in Equation G-1. The result is shown in this first row. This row is not simply the application of Equation G-2 to the population-weighted label (858 kWh/yr) of all the unmetered strata.

Table G-1. Population-Weighted Stratum Calculations

Stratum (-)	Pop-ulation (-)	Pop. Weight (-)	Sample Std Error (-)	Modeled Std Error (-)	DOE Label (kWh/yr)	Label Ratio (-)	Corrected Energy (kWh/yr)	Field Count (-)	StdErr^2 W^2*s^2/n (-)
90% Confidence interval on savings = 644 +/- 63 kWh/year (+/- 10% of savings)									
New	15832	1.000			499	1.13	563	34	600
Existing	15832	1.000			903	1.34	1207	182	862
1	5892	0.372	45	63	857	1.33	1140	15	552
4	27	0.002	123	80	503	1.25	628	3	0
10	28	0.002	43	71	552	1.27	699	2	0
18	130	0.008	331	68	567	1.27	721	4	0
23	485	0.031	107	59	624	1.29	803	33	3
30	119	0.008	94	48	697	1.30	909	6	0
34	89	0.006	42	45	725	1.31	949	3	0
36	136	0.009	80	44	733	1.31	961	8	0
37	94	0.006	52	44	735	1.31	963	7	0
39	241	0.015	105	43	740	1.31	971	3	0
40	248	0.016	89	43	740	1.31	971	4	0
41	65	0.004	306	42	759	1.32	998	2	0
42	0	0.000	40	42	765	1.32	1007	2	0
44	199	0.013	277	41	770	1.32	1014	2	0
45	13	0.001	125	41	784	1.32	1034	3	0
48	42	0.003	10	41	785	1.32	1036	2	0
57	138	0.009	182	40	815	1.32	1079	2	0
58	1,026	0.065	37	40	824	1.33	1092	4	7
59	361	0.023	198	40	828	1.33	1098	4	1
61	98	0.006	99	40	828	1.33	1098	9	0
62	51	0.003	186	40	835	1.33	1108	4	0
71	670	0.042	47	43	885	1.33	1180	4	3
78	205	0.013	123	45	905	1.34	1209	5	0
79	236	0.015	145	47	924	1.34	1237	3	0
80	110	0.007	53	47	925	1.34	1238	7	0
83	554	0.035	142	52	965	1.34	1296	6	3
92	82	0.005	238	65	1044	1.35	1410	3	0
93	814	0.051	98	66	1046	1.35	1413	12	11
95	3,679	0.232	246	72	1080	1.35	1462	20	277

[3] The sample size shown here for the existing refrigerators is only 15,832 instead of 15,979, because there were slightly fewer model numbers of demanufactured refrigerators recorded than the number demanufactured by Planergy.

Appendix H

Savings Calculations, Results, and Comparison of Temperature Difference Adjustment Methods

Appendix H

SAVINGS CALCULATIONS, RESULTS, AND COMPARISON OF TEMPERATURE DIFFERENCE ADJUSTMENT METHODS

The program savings calculation involves the integration of several data sources:

- gross total energy monitoring (1 week) for determining consumption by new and existing refrigerators and one-time measurements of ambient and compartment temperatures
- chamber testing of the new refrigerators
- population records on existing refrigerators, existing units count (EUC)
- DOE database of label-rated energy consumption (by model)
- detailed field monitoring for determining peak power usage and associated demand charges
- daily outdoor temperatures (during field testing) and long-term-average monthly outdoor temperatures for New York City
- time-of-use electrical load shapes for NYCHA developments.

Unit-level cost savings are calculated based on the difference in estimated annual-energy charges of a single existing and single new refrigerator. Annual energy charges are calculated based on estimates of annual-energy consumption and associated demand charges.

Program level savings are a total of all savings generated from each new refrigerator installed as a replacement. This is a summation of the product of unit-level savings and the corresponding model count. Estimates of confidence intervals on the savings estimate are based on a stratified analysis of sample variance.

Field Data Sample

When evaluating the relative performance of two refrigerators through a comparison of their energy consumption, absolute savings are best determined under equivalent operating conditions. In this way, differences in consumption can be attributed to differences in the refrigerators. In field testing, it is nearly always the case that operating conditions are not perfectly matched. Even with a paired-sample design, operating conditions and occupant behaviors can differ significantly from the pre-installation period to the post-installation period.

In this study, an un-paired sample of existing and new refrigerators forms the basis for all estimates of consumption. A sample of existing units represents the population of existing units and a sample of new units represents the population of new units. The sample of existing units is roughly proportional in that it is intended to direct more of the sampling resources to the more populous models. The sample is analyzed using a combination of deterministic corrections for operating conditions and stratified statistical analysis (see Appendix E.)

The deterministic corrections serve to present the measurements of consumption of new and existing units on a common ambient and internal temperature basis. Consumption is corrected to values that would result if all units had been operated at a common ambient temperature and a common internal setpoint temperature. In this first analysis, other operating characteristics, such as occupant door openings and associated food cool-downs, are assumed to be similar (on average) for the new and existing refrigerators, and do not enter into the estimate of average savings (see additional discussion in Appendix E).

Deterministic temperature corrections also serve to project the data to represent a full year of operation. The sample measurements are not equally distributed in time through-out the year. As a result, the sample-average room temperatures may not be equal to a typical yearly-average room temperature for all the replaced refrigerators. Through a determination of the annual average room temperature, the consumption can be projected to this condition and thereby better represent typical annual consumption and savings.

Filtering

The metered data can be filtered by one or all of several constraints to produce a subset of the whole database. The filtered database then becomes the new basis from which all savings calculations are made. The only filters applied in the results reported here are by control settings. The settings filter subsets the sample of new refrigerators by their temperature control setting. The resulting subset includes only those new refrigerators that have their thermostat control set to a particular value. This filter feature allows the analysis tool to look at the total savings impact caused by (1) the higher efficiency of the refrigerator and (2) the occupants' response to the campaign to encourage warmer control settings. In the savings estimates that follow, this filter will be either:

- off, no filtering by setting, or
- on, filtered such that only new refrigerators at a given control setting (i.e. 2 or 5) are included.

When filtering on control setting, an option can be selected such that the temperature correction calculation does not use the internal target but rather the internal temperatures are left as recorded in the field. In this way, the projection can be based on an annual-average ambient temperature without adjustment for the effect of compartment temperatures that differ from the internal target (usually the sample average). This is required to avoid negating the action of the settings filter through use of unwanted temperature correction.

Label Identification

DOE label ratings are identified for each existing and new refrigerator. Each unit's model number and manufacturer name are used to search through a database of DOE label ratings. Values for label rating, volume, year of manufacture, and defrost type are collected from the database.

The label ratings of all the metered refrigerators are used to develop a linear model of consumption. This model is the basis of consumption predictions for the existing units.

Stratification

Stratification is a process by which refrigerators are identified as having equivalent design and correspondingly equivalent potential for installed field performance. These refrigerators are considered equivalent for the purpose of the analysis and are grouped into a common stratum. This is done by identifying all refrigerators in the process (both metered and un-metered) that are equivalent based on the following factors:

- manufacturer
- label rating
- label volume
- label defrost type

The model numbers for the refrigerators in a stratum may not be identical. This is mainly because some manufacturers sell the same refrigerator under more than one brand name, and each brand has its own model numbering system. Portions of a model number may be used to represent features such as color, left or right hand doors, and plant and date of manufacture. Not all these variations are included for all refrigerators in the database. Damaged model-label plates on existing refrigerators and transcription errors also can cause slight differences.

Stratification is used to project the metered results to the population through knowledge of the fraction of population each stratum represents.

The stratification process is facilitated through use of the Strata Definitions data table. A sample number of rows from the Strata Definitions table is shown in Table H-1. Here a single record (row) is made for each unique model number. This includes records that originate from the metered database (Existing and New data tables) and from the EUC database of existing units that may or may not have been metered. The stratum is assigned the name (model number) of one of its members and also given a number index.

Table H-1. Strata Definitions

Strata			Refrigerator Type		Characteristics from Labels Database					
Primary		Secondary	Manufacturer	Model No.	Year(s)	Defrost	Size	Label	Proxy(s) Used If Not Matched	
(-)	(-)	(-)	(-)	(-)	(-)	(-)	(ft^3)	(kWh/yr)	(-)	(-)
X	< Min. Metered	1	aaa	< Min. Metered	N/A			820	N/A	N/A
	CTH14CYXLRWH	2	Hotpoint	CTH14CYXLLWH	1994.00	A	14.4	499	Hotpoint	CTH14CYT
X	CTH14CYXLRWH	2	Hotpoint	CTH14CYXLRWH	1994.00	A	14.4	499	Hotpoint	CTH14CYT
	CTH14CYXLRWH	2	Hotpoint	CTH14XYLLWH	1993.00	A	14.4	499	Hotpoint	CTH14CYS
X	TA10SD	3	General Electric	TA10SD	1991.00	M	9.6	470	General Electric	TA10SM
X	SSD11CBB	4	Hotpoint	SSD11CBB	1982.00	M	10.6	503	Hotpoint	SSD11CB
	SSD11CBB	4	General Electric	TA11SFB	1985.00	M	10.6	503	General Electric	TA11SF
X	RC131LRW2	5	Westinghouse	RC131LRW2	1984.00	M	13.0	504	Westinghouse	RC131G**2
X	106.860209	6	Sears	106.860209	1982.00	M	6.0	523	Kenmore	98602
	106.860209	6	Kenmore	106.8602011	1982.00	M	6.0	523	Kenmore	98602
	106.860209	6	Coldspot	86022091	1982.00	M	6.0	523	Kenmore	986022
X	RT14DKX	7	Roper	RT14DKX	1993.00	A	14.4	525	Roper	RT14DK*A*0*
	RT14DKX	7	Roper	RT14DKXB	1994.00	A	14.4	525	Roper	RT14DK*B*0*
	EAL12CT	8	Sears	106.765121	1975.00	M	12.4	540	Coldspot	7651210
	EAL12CT	8	Sears	7651210	1975.00	M	12.4	540	Coldspot	7651210
	EAL12CT	8	Sears	7651290	1975.00	M	12.4	540	Coldspot	7651290
X	EAL12CT	8	Whirlpool	EAL12CT	1975.00	M	12.4	540	Whirlpool	EAL12CT

The stratum's model name is shown in the second column. The actual recorded model manufacturer and name are recorded in the "Refrigerator Type" columns for each member of the stratum. Results of the label search in the DOE database are shown to right. Here if a proxy was determined to be acceptable (not an exact match but thought to be equivalent), the actual manufacturer and model name of the proxy are given. If the look-up yields an exact match, the proxy is identical to the original.

Metering Results by Strata

Table H-2 shows the means and standard deviations for each metered stratum. Each row represents a stratum that has a metered sample. Each row is the result of a calculation done on a set of rows (metered members in the stratum) in the Existing and New table. The rows are sorted in descending order of label rating. At the top of each table are summary calculations that show results for the three general categories of refrigerators in the program: all, new, and existing. For example, the maximum annualized consumption recorded for the new units is 974 kWh/year and minimum is 349 kWh/year.

Table H-2. Temperature-Adjusted Stratum Results

Str. (-)	Model No. (-)	Manufacturer (-)	Type (-)	Sample Size (-)	Average Energy (kWh/yr)	Median (kWh/yr)	Min (kWh/yr)	Max (kWh/yr)	Stand. Deviation (kWh/yr)	Stand. Error (kWh/yr)
Sample Weighted Averages			All	222	995	922	151	5763	595	40
			New	34	563	533	349	974	143	25
			Existing	188	1073	994	151	5763	612	45
1	< Min. Metered	aaa	Existing	15	1107	764	503	5105	1136	293
4	SSD11CBB	Hotpoint	Existing	3	686	564	561	932	214	123
10	TA10DRB	General Electric	Existing	2	578	578	535	622	61	43
18	RT12DKX	Roper	Existing	4	828	726	151	1709	662	331
23	WRT15CGA	Westinghouse	Existing	33	1019	906	546	4144	615	107
30	ATG15ONCW1	Westinghouse	Existing	6	1033	1079	683	1269	229	94
34	8660211	Sears	Existing	3	1164	1190	1082	1220	73	42
36	CTXY14MDLWH	Hotpoint	Existing	8	990	1020	637	1242	226	80
37	CTA13CJ	Hotpoint	Existing	7	888	883	702	1105	137	52
39	ET12CC1SWOO	Whirlpool	Existing	3	855	910	652	1003	182	105
40	TB13SB	General Electric	Existing	4	927	855	811	1189	178	89
41	CTN11OW-1	Westinghouse	Existing	2	1324	1324	1019	1630	432	306
42	571033364	Kenmore	Existing	2	708	708	668	748	57	40
44	TB15SGB	General Electric	Existing	2	651	651	374	928	392	277
45	ET12LKXXWOO	Whirlpool	Existing	3	857	960	609	1003	216	125
48	ET14DCXR	Whirlpool	Existing	2	923	923	913	933	14	10
57	RTG123GL	Westinghouse	Existing	2	849	849	667	1032	258	182
58	RD12C1WMGC	Gibson	Existing	4	818	849	708	867	74	37
59	RT143SC	Westinghouse	Existing	4	992	1054	456	1404	397	198
61	2539305090	Sears	Existing	9	1199	1121	812	1612	296	99
62	RT14DCYVW10	Roper	Existing	4	1179	1191	715	1617	372	186
71	ET12PCXL	Whirlpool	Existing	4	837	857	707	927	93	47
78	RT14C1WMGC	Gibson	Existing	5	1334	1276	993	1709	274	123
79	RT12C1	Gibson	Existing	3	997	994	747	1248	250	145
80	EHT141DTW	Whirlpool	Existing	7	1129	1133	976	1335	141	53
83	TB12SNB	General Electric	Existing	6	1243	1250	810	1657	347	142
92	TB14SVD	General Electric	Existing	3	2076	2133	1639	2457	412	238
93	CTA14CAB	Hotpoint	Existing	12	1346	1319	868	2031	338	98
95	EET121DT	Whirlpool	Existing	20	1223	1087	371	5763	1101	246

The first row (Stratum #1) shows results for the "less-than-minimum-metered" set of metered units. This stratum collects counts from all models that have insufficient counts to establish an independent stratum. Where the counts criterion, n_{min}, is a control factor, that can be set in the analysis tool. All adequately metered strata have a metered-sample count of greater than or equal to n_{min}. A setting of n_{min} equal to 2 is used in all the following analysis. In this case, the "less-than-minimum-metered" set has no similar refrigerators. It is the collection of the sampled models for which there is only one metered unit.

In Table H-3, the results are normalized by DOE Label rating. The fourth column is an average of the label ratios originating in the Existing and New data tables. The average of all the metered Existing refrigerators is shown as 1.33. All the new refrigerators have an average of 1.13, when filtered to only include refrigerators with a control setting of 2. This filtering is why the metered sample size is only 34.

Table H-3. Label-Normalized Stratum Results

Str. (-)	DOE Label (kWh/yr)	Sample Size (-)	Average of Ratio (-)	Median of Ratio (-)	Min. of Ratio (-)	Max. of Ratio (-)	Std. Dev. of Ratio (-)	Average Energy (kWh/yr)	Standard Deviation (kWh/yr)
All	765	216	1.30	1.20	0.27	6.64	0.61	997	381
New	499	34	1.13	1.07	0.70	1.95	0.29	563	143
Old	815	182	1.33	1.22	0.27	6.64	0.65	1078	425
1	820	15	1.35	1.06	0.62	2.74	0.50	1107	412
4	503	3	1.36	1.12	1.11	1.85	0.42	686	214
10	552	2	1.05	1.05	0.97	1.13	0.11	578	61
18	567	4	1.46	1.28	0.27	3.01	1.17	828	662
23	624	33	1.63	1.45	0.88	6.64	0.98	1019	615
30	697	6	1.48	1.55	0.98	1.82	0.33	1033	229
34	725	3	1.61	1.64	1.49	1.68	0.10	1164	73
36	733	8	1.35	1.39	0.87	1.70	0.31	990	226
37	735	7	1.21	1.20	0.95	1.50	0.19	888	137
39	740	3	1.16	1.23	0.88	1.35	0.25	855	182
40	740	4	1.25	1.15	1.10	1.61	0.24	927	178
41	759	2	1.74	1.74	1.34	2.15	0.57	1324	432
42	765	2	0.93	0.93	0.87	0.98	0.07	708	57
44	770	2	0.85	0.85	0.49	1.21	0.51	651	392
45	784	3	1.09	1.22	0.78	1.28	0.28	857	216
48	785	2	1.18	1.18	1.16	1.19	0.02	923	14
57	815	2	1.04	1.04	0.82	1.27	0.32	849	258
58	824	4	0.99	1.03	0.86	1.05	0.09	818	74
59	828	4	1.20	1.27	0.55	1.70	0.48	992	397
61	828	9	1.45	1.35	0.98	1.95	0.36	1199	296
62	835	4	1.41	1.43	0.86	1.94	0.45	1179	372
71	885	4	0.95	0.97	0.80	1.05	0.11	837	93
78	905	5	1.47	1.41	1.10	1.89	0.30	1334	274
79	924	3	1.08	1.08	0.81	1.35	0.27	997	250
80	925	7	1.22	1.22	1.05	1.44	0.15	1129	141
83	965	6	1.29	1.30	0.84	1.72	0.36	1243	347
92	1044	3	1.99	2.04	1.57	2.35	0.39	2076	412
93	1046	12	1.29	1.26	0.83	1.94	0.32	1346	338
95	1080	20	1.13	1.01	0.34	5.34	1.02	1223	1101

Program Savings

Calculation of program level savings requires projecting the results of the metered sample onto the population of existing refrigerators. In this way, the per-unit energy savings in each stratum is multiplied by its corresponding population as recorded in the EUC database.

Energy consumption is calculated stratum-by-stratum and on a per-unit basis as shown in Table H-4.[1] Due to logistical limitations in the metering work, not all of the most populous strata have a metered sample. These strata cannot be directly represented by metered results. Approximately 37% of the existing refrigerators are in un-metered strata, arbitrarily assigned to Stratum 1.

The average consumption of existing units, for both metered and unmetered strata, is calculated through use of a regression model. The regression model is a linear predictor of temperature-corrected consumption as a function of unit label rating (see Figure 4.4 of Section 4.4). When an existing unit does not have a label rating, the simple average consumption of the total metered sample (for existing units) is used as its consumption level. The population of new refrigerators installed in the program is represented by the average of the metered sample of new refrigerators at the specified control setting.

Per-unit energy savings are calculated as the simple difference in temperature-adjusted of the existing and new model. Also, an estimate of demand savings is made (see Appendix G). This is repeated for each stratum. These stratum-level components of savings are then totaled and divided by the total number of units to produce an estimate of total savings (per replacement unit).

[1] The sample size shown here for the existing refrigerators is only 15,832 instead of 15,979, because there were slightly fewer model numbers of demanufactured refrigerators recorded than the number demanufactured by Planergy.

Table H-4. Consumption and Savings by Stratum

Str. No.	Model	Pop. Wgt.	DOE Label	Label Ratio	Corrected Energy
(-)	(-)	(-)	(kWhr/yr)	(-)	(kWhr/yr)
Exististing			903	1.34	1207
New			499	1.13	563
1	5892	0.372	857	1.33	1140
2	15832	1.000	499	1.13	563
4	27	0.002	503	1.25	628
10	28	0.002	552	1.27	699
18	130	0.008	567	1.27	721
23	485	0.031	624	1.29	803
30	119	0.008	697	1.30	909
34	89	0.006	725	1.31	949
36	136	0.009	733	1.31	961
37	94	0.006	735	1.31	963
39	241	0.015	740	1.31	971
40	248	0.016	740	1.31	971
41	65	0.004	759	1.32	998
42	0	0.000	765	1.32	1007
44	199	0.013	770	1.32	1014
45	13	0.001	784	1.32	1034
48	42	0.003	785	1.32	1036
57	138	0.009	815	1.32	1079
58	1026	0.065	824	1.33	1092
59	361	0.023	828	1.33	1098
61	98	0.006	828	1.33	1098
62	51	0.003	835	1.33	1108
71	670	0.042	885	1.33	1180
78	205	0.013	905	1.34	1209
79	236	0.015	924	1.34	1237
80	110	0.007	925	1.34	1238
83	554	0.035	965	1.34	1296
92	82	0.005	1044	1.35	1410
93	814	0.051	1046	1.35	1413
95	3679	0.232	1080	1.35	1462

Savings and Comparison of Temperature Correction Methods

Calculations of program savings are presented here under seven different sets of assumptions. These calculations illustrate how assumptions about control settings and temperature-correction methods affect the savings estimate. The results of these seven runs are summarized in Table H-5. The columns present the label ratio and annual consumption for the existing and new units. This is followed by the annual unit-level savings per year (energy, demand, and total) for all the refrigerators in the replacement program. These totals or averages reflect the population counts for each model of existing refrigerator. A description of each run, corresponding to each row of the table, follows.[2]

Table H-5. Consumption, Label Ratio, and Savings

Run Description	Old			New			Savings	Project Savings Per Unit		
	Ratio (-)	Label (kWh/yr)	Use/Yr (kWh/yr)	Ratio (-)	Label (kWh/yr)	Use/Yr (kWh/yr)	Per Unit (kWh/yr)	Energy ($/yr)	Demand ($/yr)	Total ($/yr)
Linear, $T_{int\text{-}target}$ = 39.3 °F	1.353	903	1222	1.289	499	643	579	$20.49	$18.82	$39.32
2's only	1.336	903	1207	1.129	499	563	644	$22.78	$20.93	$43.71
5's only	1.336	903	1207	1.500	499	749	458	$16.22	$14.90	$31.12
Cond, $T_{int\text{-}target}$ = 39.3 °F	1.323	903	1195	1.252	499	625	570	$20.19	$18.55	$38.75
2's only	1.325	903	1197	1.119	499	558	639	$22.60	$20.76	$43.37
5's only	1.325	903	1197	1.463	499	730	467	$16.53	$15.19	$31.72
No correction, 2's only	1.327	903	1199	1.146	499	572	627	$22.20	$20.39	$42.59

Run Descriptions

1. **Linear, $T_{int\text{-}target}$ = 39.3°F:** Refrigerator consumption is corrected using the linear correction approach with target temperatures of 78.7°F ambient (predicted annual average kitchen temperature) and 39.3°F internal (surface-area weighted average of the compartment temperatures for all the existing units). Linear corrections are made to the consumption of the new and existing units using Equation E-5.

2. **Linear, 2s only:** Here the sample of new refrigerators is filtered such that only those at a control setting of 2 are included in the analysis. When filtering on control setting, the temperature correction calculation does not use the 39.3°F target. Rather, the internal temperatures are left as recorded in the field. The projection is based on a target ambient

[2] Some of the label ratios shown in Table H-5 are slightly different than those reported in the body of the report. This is because those reported here are the average of the individual label-ratios, whereas those reported in Section 4 are the average consumption divided by the average label ratio.

temperature without adjustment to the compartment temperatures. This ambient-only correction avoids negating the effect of the control-setting filter. Note the slight changes in the existing-units label ratio and consumption, when changing from a base case to a filtered case, are due to the change the temperature correction method that is associated with the settings filter (ambient-only correction).

3. **Linear 5s only:** This is similar to the 2s only case except only those new refrigerators at a control setting of 5 are included in the analysis.

4. **Conduction, $T_{int\text{-}target}$ = 39.3°F:** This is similar to the base case (1) above except that the conduction-correction approach is used (see Equations 1 and 2).

5. **Conduction, 2s only:** Here again the conduction-correction approach is used. In a way equivalent to the 2s-only case above, the sample of new units are filtered such that only those at a setting of 2 are included in the analysis.

6. **Conduction, 5s only:** Similar to case 5 above except that only those new refrigerators at a control setting of 5 are included in the analysis.

7. **No correction, 2s only:** Here there is no temperature correction applied to the consumption data. Raw field-consumption data is used. The sample of new units is filtered such that only those at a control setting of 2 are included in the analysis.

Discussion

The results in row two (2s only) is a subset of the data shown in Table H-4. It indicates the 644 kWh/yr savings by the units at a setting of 2, more than a 50% reduction in energy and demand costs from the annual costs of the existing units. Other field studies have typically reported consumption (and hence the corresponding savings) at levels 90% of label rating (0.9 * (911 - 499) = 371 kWh/yr expected savings for this field study). In this program, the per-unit savings of 644 kWh/yr (2s only) are higher than the savings of 412 kWh/yr predicted by the labels of the existing and new units. The higher savings are due mainly to the higher-than-label consumption recorded for both the new and existing units. In addition, the filtering of the new units (such that only those at a setting of 2 are included) reduces the estimated consumption of the population of new units.

A factor that reduces the savings in this study is the significantly larger volume and associated consumption of the new units. If the consumption of the existing units is scaled with volume, so as to be comparable with the 14.4 ft^3 of the new units, the corresponding savings would be 815 kWh/yr.

$$815 = 1206 * \frac{14.4}{12.6} - 563$$

Comparison of Methods

The difference in savings calculated using each of the three correction methods (Linear, Conduction, and No-Correction) is less than 15 kWh/yr. This small difference can be understood in part because the annual-average temperature targets are not strongly different from those naturally occurring in the metered database (see Table H-6). Differences between the correction methods could potentially be more visible if projected to a more distant annual-average temperature target.

Table H-6. Field-Measured and Target Temperatures

Refrigerator Group	Interior (°F)	Ambient (°F)
New (2s)	40.3	78.6
New (5s)	38.1	75.9
Existing	39.3	79.1
Target	39.3	78.7

The runs that were selectively filtered by control setting showed strong differences in consumption. Those set at 2 showed consumption levels 149 kWh/yr less than those set at 5 (5 is colder than 2). Due to this strong impact, the final savings calculation uses a blended (from 2s and 5s) result that is weighted based on survey data (see Section 2.4). The survey indicates the average control setting used by the occupants (after being encouraged to use a setting of 2).

Appendix I

COMPARISON OF THE LABEL RATIOS TO THOSE FROM OTHER PROGRAMS

Refrigerator field consumption (expressed as a ratio to the DOE label ratings[1]) observed in this program is significantly higher than what has been observed in other studies. The issue is that the raw field data show consumption/label ratios of 1.34 for all existing units and 1.16 for new units (new-unit controls set[2] to level 2). These ratios stand in contrast to the reported ratio of 0.89 from the Bonneville Power Administration's ELCAP field monitoring program (Ross 1991). Factors that explain high ratios in the NYPA study are discussed in the following sections.

HIGH TEMPERATURE

The estimated annual-average indoor daytime temperature for the apartments monitored by the program is 78.7°F. This is significantly higher than the 69°F average-indoor temperature reported in the ELCAP study of single family housing.

Table I-1 below shows the consumption/label ratios that result from applying a linear temperature correction (see Appendix E) to the field data.[3] The raw field sample (uncorrected and unweighted by new unit populations) is shown in the first row. The average ΔT is shown in brackets ([]). In the second row each unit in the sample is projected to the annual-average ambient conditions of 78.7°F for both new and existing units (ambient projection only, internal temperatures left as recorded in the field

[1] DOE label ratings refer to controlled consumption testing (no door openings) at an ambient temperature of 90°F. These label ratings are not intended to accurately predict field consumption but rather serve in a way analogous to mpg ratings for automobiles.
[2] New refrigerators are being installed with temperature control settings set at level 2.
[3] Some of the label ratios shown in **Error! Reference source not found.** are slightly different than those reported in the body of the report. This is because those reported here are the average of the individual label-ratios, whereas those reported in Section 5 are the average consumption divided by the average label ratio.

monitoring). In the third row, the sample of existing units is weighted by the corresponding populations of existing units removed in the developments. In the fourth row, the projection is to an ambient temperature of 69°F.

Table I-1. Consumption/Label Ratios for Various Conditions

Condition	Existing Refrigerators	New Refrigerators
Raw sample	1.35 [ΔT = 39.8 °F]	1.15 [ΔT = 42.5 °F]
Projected to 78.7 °F	1.33 [ΔT = 39.4 °F]	1.13 [ΔT = 41.5 °F]
Projected to 78.7 °F &	1.33 [ΔT = 39.4 °F]	1.13 [ΔT = 41.5 °F]
Projected to 69.0 °F &	1.00 [ΔT = 29.7 °F]	0.86 [ΔT = 31.8 °F]
Difference (in 2 rows above)	0.33	0.27
Percent of discrepancy	0.33/(1.33-0.89)=75%	0.27/(1.13-0.89)=112%

Using this method, the temperature effect accounts for approximately 75% of the original discrepancy for the existing units and 112% for the new units. However, it must be noted that this assumes temperature control settings of 2, reducing the label ratios for the new units. The observed control settings were closer to 3.1, resulting in a label ratio of 1.26. Consequently, the field-measured label ratios would be higher, and the temperature effect would account for only about 81% of the discrepancy after projection to the 69°F ambient.

HIGH LEVELS OF INSULATION

Another distinct characteristic of the field sample that can cause relatively high consumption/label ratios is the higher-than-normal levels of insulation in the new units. This is because label-testing procedures do not measure door-opening effects. A thought experiment with a perfectly insulated refrigerator gives a label rating of zero from chamber testing, yet, in the real world, door-openings and associated food and air cool-downs would result in cooling loads on the compressor. In this perfect-refrigerator extreme, the ratio of consumption to label would be infinite.

As a refrigerator gets better at resisting conductive loads, the fraction of total consumption that is related to cool-down loads gets higher (assuming the compressor technology remains the same). It is reasonable to expect that this could account for any of the remaining difference between this program and the ELCAP study.

For the existing units, this high-insulation argument does not apply. However, there may be a similar, but only second-order effect, related to the relatively small size of the existing units in the developments. If it is assumed conductive loads decrease faster with volume than cool-down loads, the same argument could be used to make the case that smaller refrigerators would tend to have higher consumption/label ratios than larger ones. However, this assumption is debatable and probably does not account for a significant fraction of discrepancy for the existing units.

DEGRADATION

Finally, for the existing units the remaining portion of the discrepancy may be attributable to degradation. There is not data to support this, but it is reasonable to assert that the existing units in the developments are older than those found in the other single-family field studies. The higher age of refrigerators may be responsible for a correspondingly higher levels of degradation in their performance.

Appendix J

RAW AND TEMPERATURE-ADJUSTED FIELD DATA

Appendix J

RAW AND TEMPERATURE-ADJUSTED FIELD DATA

Table J-1 contains the primary metered, measured, and surveyed field data supplied to PNNL by Synertech and NYPA for each metered refrigerator. Each row represents a metered refrigerator. The refrigerators are presented in the chronological order they were metered. The existing refrigerators are listed first, and the new refrigerators (Hotpoint CTH14CYXL*) start in the middle of page J-8.

The Audit columns show the date the data collection was started, the number of days data was collected, and the name of the housing development. The Refrigerator Type columns contain the brand name and model number. The Features column contains the type of defrost function. The Frost and Food Loading columns contain the observed thickness of frost in the freezer and the estimated percentage full of the fresh-food and freezer compartments, respectively. The Temperature Control columns indicate the control setting of the fresh-food compartment and the maximum of the setting range. The Start and End Temperature columns indicate the snapshot temperatures recorded for the ambient air, fresh-food and freezer compartments at the beginning and end of the metering period, respectively. The Raw Usage columns show the energy consumed (W-hr) by the refrigerator and its average load (W) during the monitoring period.

Finally, several key computed results are also indicated. The column labeled I (for Included) is a flag indicating whether the data point was included in the analysis (1 indicates it was included, 0 rejected). The Raw Annualized Consumption is simply the metered energy consumption projected to a year's time (it is conveniently calculated as 8760 hours per year times the average load in Watts, divided by 1000). The Adjusted Annualized Consumption is adjusted for the difference between the average of the ambient temperatures at the start and end of the metering period for the refrigerator and the estimated annual average ambient air temperature of 78.7°F. Finally, the Fraction (of Label Rating) is the ratio of the Adjusted Annualized Consumption to the manufacturer's DOE-label rating, based on looking up the model number in the AHAM refrigerator database. If this is "N/A", then no label rating could be found because either 1) no corresponding or similar model number could be found in the database, or 2) label ratings were not required in the year it was manufactured. If it is blank, no label was looked up (because the refrigerator was not included in the analysis).

Table J-1. Raw and Temperature-Adjusted Field Data

Audit			Refrigerator Type		Features	Frost	Food Loading		Temp Control		Temperatures (Start)			Temperatures (End)			Raw Usage		I	Annualized Consumption		
Date (-)	Duration (hr)	Site (-)	Manufacturer (-)	Model No. (-)	Defrost (-)	Accum (In)	Refrig. (%)	Freezer (%)	Setting (-)	Scale (-)	Ambient (°F)	Refrig. (°F)	Freezer (°F)	Ambient (°F)	Refrig. (°F)	Freezer (°F)	Energy (Whr)	Watts (W)	(-)	Raw (kWh/yr)	Adjusted (kWh/yr)	Fraction (-)
1/5/96	96	Edenwald	Whirlpool	ET12PCX	Manual	0.3	25	40	3.5	5.0	72.8	37.2	5.9	72.8	37.2	5.9	8987	93.4	1	818	927	1.05
1/5/96	171	Edenwald	Whirlpool	FET122DTWL	Manual	1.0	30	30	4.5	5.0	71.0	39.4	11.0	71.0	41.5	23.9	20905	122.3	1	1072	1295	1.20
1/12/96	313	Edenwald	Hotpoint	CTA14CAB		2.0	80	40	8.0	9.0	68.1	45.2	20.6	78.8	44.3	13.8	29229	93.2	1	817	931	0.89
1/12/96	174	Edenwald	Hotpoint	CTA14CAB		1.0	20	80	9.0	9.0	89.1	44.3	24.0	76.3	48.0	24.0	33186	191.1	1	1674	1521	1.45
1/12/96	162	Edenwald	Westinghouse	MRT15CNBW		0.0	40	15	0.0	0.0	67.9	41.7	19.3	68.1	39.6	18.0	16737	103.1	1	903	1192	1.91
1/12/96	174	Edenwald	Westinghouse	WRT15CGAWO	Automatic	0.0	50	40	6.0	9.0	66.4	49.6	22.3	71.9	49.8	10.3	15560	89.5	1	784	1043	1.67
1/12/96	171	Edenwald	Westinghouse	CTN11OWK-1	Automatic	0.0	70	15	1.0	9.0	76.2	40.0	12.5	77.4	40.2	9.5	19057	111.6	1	977	1019	1.34
1/12/96	38	Edenwald	Hotpoint	CTA12CBC	Manual	0.0	50	20	1.0	9.0	77.8	45.9	4.3	77.8	45.9	4.3	5406	141.7	0	1241	1266	1.31
1/12/96	167	Edenwald	Whirlpool	EET122DT	Manual	0.3	50	25	2.0	5.0	77.0	45.7	15.8	70.2	46.2	27.6	18331	109.8	1	961	1104	1.02
1/12/96	160	Edenwald	Hotpoint	CTA12CBC	Manual	0.3	25	10	1.0	9.0	97.2	49.2	19.2	73.6	46.4	17.6	17279	108.2	1	948	810	0.84
1/12/96	171	Edenwald	Westinghouse	CTN11OW-1	Automatic	0.3	25	35	2.0	9.0	68.8	42.5	12.7	72.0	44.5	25.4	25644	149.6	1	1311	1630	2.15
1/12/96	159	Edenwald	Westinghouse	WRT15CGAWO	Automatic	0.0	60	90	3.0	9.0	70.6	42.2	29.9	73.0	40.1	14.1	12775	80.4	1	705	831	1.33
1/12/96	162	Edenwald	Westinhouse	AGT15ONLW2		0.0	20	50	6.0	9.0	78.3	46.0	28.3	74.0	56.0	35.5	18401	113.4	1	993	1076	1.54
1/12/96	159	Edenwald	Whirlool	EET122DT	Manual	0.5	25	15	5.0	5.0	69.3	34.6	14.4	72.1	35.9	11.4	20030	126.2	1	1105	1318	1.22
1/12/96	172	Edenwald	Hotpoint	CTA14CBC		1.0	40	40	5.0	9.0	81.2	45.1	19.7	77.2	65.9	19.1	17263	100.6	1	881	868	0.83
1/12/96	172	Edenwald	Westinghouse	WRT15CGAWO	Automatic	0.0	70	40	6.0	6.0	73.8	59.3	25.8	86.1	57.9	42.1	20511	119.5	1	1046	1000	1.60
1/19/96	167	Edenwald	Hotpoint	CTXY14MDLWH	Manual	0.0	30	50	9.0	9.0	70.4	41.4	16.6	70.5	40.6	14.7	18276	109.7	1	961	1175	1.60
1/19/96	159	Edenwald	Whirlpool	ET12PCXWRO	Manual	0.5	40	35	4.0	5.0	72.4	49.5	16.1	80.2	48.0	21.5	17010	107.3	1	940	1003	1.35
1/19/96	167	Edenwald	Hotpoint	CTA14CAB	Manual	4.0	100	100	9.0	9.0	67.9	36.7	13.0	73.9	44.1	11.6	32425	193.7	1	1697	2031	1.94
1/19/96	161	Edenwald	Whirlpool	EET122DTWRO	Manual	0.0	50	90	3.5	5.0	73.2	46.5	15.6	78.2	48.7	16.3	18942	117.5	1	1029	1111	1.03
1/19/96	161	Edenwald	Whirlpool	ET12CC	Manual	1.0	20	20	4.0	5.0	80.2	53.0	24.8	94.6	53.8	27.7	14878	92.3	1	808	652	0.88
1/19/96	173	Edenwald	Westinghouse	ATG15ONLW2		0.0	60	25	7.0	9.0	72.1	48.1	21.4	81.8	43.8	23.3	12858	74.5	1	653	683	0.96
1/19/96	161	Edenwald	Whirlpool	EET-122DTWRO	Manual	1.0	75	50	1.0	5.0	88.3	54.0	27.0	78.6	54.6	23.0	10914	67.8	1	594	520	0.48
1/19/96	161	Edenwald	Westinghouse	ATN13OWKI	Automatic	0.0	50	40	1.5	5.0	78.5	52.0	31.4	80.9	49.5	24.1	9515	59.1	1	518	503	0.62
1/19/96	169	Edenwald	Whirlpool	EET-122DT	Manual	1.0	40	30	2.5	5.0	73.9	50.1	20.0	82.4	51.1	20.8	20948	123.8	1	1085	1101	1.02
1/19/96	169	Edenwald	Hotpoint	CTH14CYXLRWH	Automatic	0.0	35	15	5.0	9.0	71.0	46.5	17.4	79.9	47.1	24.0	13259	78.3	0	686	747	1.50
1/19/96	161	Edenwald	Hotpoint	CTH14CYXLRWH		0.0	50	50	4.0	9.0	72.1	45.0	18.8	73.9	46.2	16.3	15345	95.4	0	835	968	1.94
1/25/96	164	Edenwald	Whirlpool	ET12PCXL		0.3	35	10	3.5	5.0	76.6	39.4	13.4	70.0	44.4	21.3	14179	86.7	1	759	866	0.98
1/25/96	24	Edenwald	Whirlpool	EET122DTWRO		0.0	50	90	3.5	5.0	76.1	38.6	13.9	76.1	38.6	13.9	2791	117.9	0	1033	1094	1.01
1/26/96	139	Edenwald	Whirlpool	ET12PCXWRO	Manual	3.0	70	25	2.0	5.0	84.1	50.6	21.5	94.4	47.5	21.5	18475	133.3	1	1167	910	1.23
1/26/96	141	Edenwald	Whirlpool	ET12PCXL		0.0	50	70	3.5	5.0	79.7	39.8	29.8	79.7	39.8	29.8	14004	99.0	1	867	847	0.96
1/26/96	160	Edenwald	Hotpoint	CTA14CAB	Manual	4.0	100	100	9.0	9.0	77.4	39.5	32.6	77.4	39.5	32.6	28360	177.8	0	1558	1608	1.54
1/26/96	143	Edenwald	Whirlpool	EET122DTWRO	Manual	0.0	50	90	3.5	5.0	76.8	36.3	27.6	76.8	36.3	27.6	16771	116.9	1	1024	1070	0.99
2/8/96	187	Mott Haven	Whirlpool	ET12LKXXWOOO	Automatic	0.0	50	40	2.0	5.0	80.3	52.0	19.5	76.6	49.4	26.0	21282	113.7	1	996	1003	1.26
2/8/96	187	Mott Haven	Whirlpool	ET12LKXXWOO	Automatic	0.0	25	10	3.0	5.0	78.8	48.9	9.1	78.5	51.2	22.9	20444	109.4	1	959	960	1.22
2/8/96	186	Mott Haven	Hotpoint	CTA12CAB	Automatic	1.0	50	90	9.0	9.0	82.0	40.7	19.5	79.8	40.8	12.6	23628	126.8	1	1111	1059	1.10
2/8/96	187	Mott Haven	Hotpoint	CTA14CAB	Automatic	2.0	50	20	4.0	9.0	82.1	50.7	14.2	81.1	46.8	19.0	29380	157.4	1	1379	1287	1.23
2/8/96	499	Mott Haven	General Electric	TA10DRB	Manual	0.0	0	0	9.0	9.0	80.4	45.9	14.4	75.8	37.5	12.5	30066	60.2	1	528	535	0.97
2/9/96	480	Mott haven	Westinhouse	WRT15CGAWO	Automatic	0.0	60	50	1.0	7.0	78.2	47.0	21.2	76.3	45.0	15.0	53919	112.3	1	984	1021	1.64
2/9/96	2	Mott Haven	Roper	T12DKYAWOO	Automatic	0.0	50	75	1.0	5.0	71.2	49.5	18.5	70.0	47.8	15.5	126	63.8	0	559	706	1.25
2/9/96	167	Mott Haven	Hotpoint	CTA14CAB	Manual	0.5	80	80	9.0	9.0	68.6	43.4	20.7	68.0	49.7	20.9	25416	152.4	1	1335	1796	1.72

Audit			Refrigerator Type		Features	Frost	Food Loading		Temp Control		Temperatures (Start)			Temperatures (End)			Raw Usage		I	Annualized Consumption		
Date (-)	Duration (hr)	Site (-)	Manufacturer (-)	Model No. (-)	Defrost (-)	Accum (In)	Refrig. (%)	Freezer (%)	Setting (-)	Scale (-)	Ambient (°F)	Refrig. (°F)	Freezer (°F)	Ambient (°F)	Refrig. (°F)	Freezer (°F)	Energy (Whr)	Watts (W)	(-)	Raw (kWh/yr)	Adjusted (kWh/yr)	Fraction (-)
2/16/96	310	Mott Haven	Westinghouse	WRT15CGA20	Automatic	0.0	80	40	4.5	9.0	76.5	44.9	27.9	77.0	39.0	24.0	28395	91.5	1	801	841	1.35
2/16/96	312	Mott Haven	Roper	RT14DCYVW10	Automatic	0.0	80	90	5.0	5.0	82.3	48.1	22.2	79.0	40.0	20.0	46572	149.4	1	1309	1250	1.50
2/16/96	310	Mott Haven	Hotpoint	CTA12CAB	Automatic	0.0	60	40	5.0	9.0	80.2	47.7	14.7	78.0	45.0	12.0	34099	109.9	1	963	954	0.99
2/16/96	310	Mott Haven	Hotpoint	CTA12CAB	Manual	0.5	80	70	6.0	9.0	82.4	59.0	24.1	78.0	53.0	23.0	53369	172.1	1	1508	1441	1.49
2/16/96	2	Mott Haven	Hotpoint	CTA14CAB	Manual	0.5	20	30	5.0	9.0	76.6	47.8	-1.4	73.4	46.0	-3.0	325	200.0	0	1752	1899	1.82
2/16/96	311	Mott Haven	Hotpoint	CTA12CAB	Manual	0.5	60	60	2.0	9.0	81.3	43.6	25.4	79.0	56.0	27.0	61185	196.8	1	1724	1657	1.72
2/17/96	308	Mott Haven	Westinghouse	WRT15CGA20	Automatic	0.0	60	20	9.0	9.0	74.0	39.4	12.2	74.0	39.4	12.2	24391	79.3	1	694	772	1.24
2/29/96	164	Mott Haven	Roper	RT14DCYVW10	Automatic	0.0	50	70	- 3.5	5.0	77.0	36.0	7.0	73.6	42.9	18.8	12383	75.7	1	663	715	0.86
2/29/96	167	Mott Haven	GE	TB14SWB	Manual	0.0	20	70	2.0	9.0	73.0	54.0	34.0	79.8	45.3	19.1	29309	175.3	1	1536	1639	1.57
2/29/96	168	Mott Haven	Hotpoint	CTA14CAB	Manual	0.3	75	90	5.0	9.0	74.6	37.0	32.0	73.5	50.5	27.2	25009	149.3	1	1308	1482	1.42
3/ 8/96	321	Gompers	Sears	2539305316		0.0	70	90	9.0	9.0	71.4	47.5	20.9	77.4	44.0	25.1	52566	164.0	1	1436	1612	1.95
3/ 8/96	308	Gompers	Whirlpool	EET12DT	Automatic	0.0	50	50	5.0	5.0	80.3	48.4	31.2	74.6	52.4	21.2	36773	119.2	1	1044	1083	1.00
3/ 8/96	309	Gompers	Whirlpool	EET122DT	Automatic	2.0	70	60	3.0	5.0	74.8	44.7	34.1	76.6	49.9	20.5	33159	107.4	1	941	1024	0.95
3/ 8/96	309	Gompers	Westinghouse	WRT15CGAWO	Automatic	0.0	80	50	6.0	9.0	73.8	42.1	22.2	75.7	45.2	19.9	28878	93.6	1	820	908	1.45
3/ 8/96	310	Gompers	Whirlpool	ET12CCLSWOO	Manual	0.0	80	90	3.0	5.0	73.4	47.3	30.7	75.8	47.3	30.7	23282	75.0	1	657	740	1.01
3/ 8/96	309	Gompers	Whirlpool	EET122DTW20	Manual	0.0	60	40	3.0	5.0	74.5	50.7	25.8	73.2	45.0	21.0	176912	573.1	1	5020	5763	5.34
3/22/96	148	Brevoort	GE	TB13SLCL	Automatic	0.3	60	20	2.5	9.0	85.2	42.1	22.3	83.4	47.7	20.5	13612	91.8	1	804	708	1.02
3/29/96	310	Morris	Westinghouse	ATG15ONCW1	Automatic	0.0	95	90	7.0	9.0	82.5	50 1	25.8	79.5	43.6	17.2	47549	153.3	1	1343	1269	1.82
3/29/96	310	Morris	GE	TB14SVD	Manual	2.0	65	0	6.0	9.0	82.9	46.5	19.9	81.6	48.7	35.7	82619	266.5	1	2334	2133	2.04
3/29/96	310	Morris	Kenmore	2539305090	Automatic	0.0	40	80	4.0	9.0	85.8	51.0	27.0	76.6	46.0	23.6	31900	102.8	1	900	843	1.02
5/ 8/96	841	Wald	Westinghouse	MRT15CNCZO	Manual	0.0	5	10	9.0	9.0	70.7	41.7	15.8	73.9	35.2	8.4	55917	66.5	1	583	672	1.08
5/ 8/96	841	Wald	CTH14CYXLRWH	TB14SAB	Manual	3.0	40	10	4.0	9.0	74.8	49.1	18.9	80.1	48.7	29.0	95413	113.5	1	994	1028	0.98
5/ 9/96	168	Fulton	Whirlpool	EET122DTWRO	Manual	0.0	50	50	4.0	5.0	74.3	48.9	16.7	72.6	43.2	19.9	19145	66.7	1	584	672	0.62
5/ 9/96	168	Fulton	Sears	25390305396	Automatic	0.0	30	5	8.0	9.0	74.6	44.0	15.8	68.2	39.8	9.4	17860	77.8	1	681	812	0.98
5/ 9/96	169	Fulton	Hotpoint	CTA14CAB	Manual	1.0	25	15	5.0	9.0	74.0	47.4	19.2	70.7	47.8	19.1	19396	117.5	1	1030	1222	1.17
5/ 9/96	167	Fulton	Westinghouse	WRT15CGAWO	Automatic	0.0	35	5	4.5	9.0	77.5	49.8	25.1	71.6	47.9	16.4	10806	125.4	1	1099	1233	1.98
5/ 9/96	167	Fulton	Whirlpool	ET14CC	Manual	0.0	30	5	5.0	5.0	73.9	42.1	4.0	73.5	37.7	8.2	18349	52.9	1	464	516	0.66
5/ 9/96	125	Fulton	Sears	2539305396	Automatic	0 0	40	60	3.0	9.0	70.7	42.5	21.2	70.7	42.5	21.2	16439	103.8	1	909	1121	1.35
5/ 9/96	167	Fulton	Sears	2539305396	Automatic	0.0	50	70	4.0	9.0	76.6	48.7	21.9	72.9	50.5	27.2	22083	132.3	1	1159	1298	1.57
5/ 9/96	310	Fulton	GE	TA212YBW30	Manual	3.0	25	0	4.0	9.0	73.8	43.9	22.1	80.5	45.7	21.4	18312	59.0	1	517	537	N/A
5/ 9/96	168	Roosevelt	Whirlpool	EET122DTWLO	Manual	0.3	65	10	5.0	5.0	75.4	46.3	21.5	79.2	43.1	9.6	23536	140.1	1	1227	1269	1.18
5/16/96	144	Bronxdale	Hotpoint	CTXY14CPGWH	Automatic	0.0	65	25	8.0	9.0	68.1	44.5	20.4	69.0	44.8	22.2	9185	64.0	1	561	744	1.01
5/16/96	144	Bronxdale	GE	N/A (GE)	Manual	5.0	40	5	2.0	9.0	69.1	41.6	-1.6	75.2	47.4	18.8	14053	97.8	1	857	1002	N/A
5/16/96	165	Fulton	Hotpoint	CTA14CAB		0.0	80	90	6.0	9 0	70.1	47.0	23.8	70.1	47.0	23.8	20547	124.5	1	1091	1396	1.33
5/16/96	146	Fulton	Hotpoint	CTA14CAB	Manual	0.0	65	35	7.0	9.0	71.8	45.8	18.4	71.8	45.8	18.4	18784	128.8	1	1128	1351	1.29
5/16/96	118	Tompkins	GE	TA10DNB	Automatic	2.0	10	20	1.0	9.0	67.8	45.6	28.2	79.2	48.1	27.5	7161	60.7	1	532	622	1.13
5/16/96	118	Tompkins	Westinghouse	RNH24RT1	Manual	0.0	4025		2.0	9.0	76.3	49.0	24.7	81.3	46.5	27.9	20046	170.0	1	1489	1485	N/A
5/21/96	55	Roosevelt	Whirlpool	EET122DTWRO	Manual	0.0	40	40	1.0	5.0	86.2	51.1	17.3	83.7	53.0	23.7	5565	100.5	1	880	748	0.69
5/21/96	46	Roosevelt	Whirlpool	EET122DTWRO	Manual	0.0	75	80	4.0	5.0	85.0	56.8	16.9	86.7	62.7	38.8	6891	150.8	0	1321	1050	0.97
5/21/96	46	Roosevelt	Hotpoint	CTXY14CPCLWH	Automatic	0.0	10	5	9.0	9.0	84.8	54.9	22.4	80.8	40.1	15.1	5254	113.6	0	995	903	1.23

Audit			Refrigerator Type		Features	Frost	Food Loading		Temp Control		Temperatures (Start)			Temperatures (End)			Raw Usage		I	Annualized Consumption		
Date (-)	Duration (hr)	Site (-)	Manufacturer (-)	Model No. (-)	Defrost (-)	Accum (in)	Refrig. (%)	Freezer (%)	Setting (-)	Scale (-)	Ambient (°F)	Refrig. (°F)	Freezer (°F)	Ambient (°F)	Refrig. (°F)	Freezer (°F)	Energy (Whr)	Watts (W)	(-)	Raw (kWh/yr)	Adjusted (kWh/yr)	Fraction (-)
5/21/96	188	Tompkins	Roper	RT14DKYBW10	Automatic	0.0	60	10	3.0	5.0	87.0	60.4	21.5	75.1	49.9	16.2	17522	93.1	1	816	764	1.37
5/21/96	188	Tompkins	Westinghouse	MRT11CRBWO	Automatic	0.0	90	65	7.0	9.0	86.6	57.3	18.6	79.5	48.7	17.3	13316	70.7	1	700	624	1.12
5/22/96	358	Bronxdale	Westinghouse	WRT12OGCW4	Manual	0.0	15	0	7.0	9.0	80.0	41.8	8.3	78.1	46.2	7.8	28161	78.6	1	688	683	0.96
5/22/96	359	Bronxdale	Westinghouse	MRT15CGAWO	Automatic	0.0	65	65	8.0	9.0	85.2	48.4	18.3	80.6	46.2	17.8	34067	94.9	1	831	752	1.20
5/23/96	143	Roosevelt	Whirlpool	EET122DTWRO	Manual	0.0	50	40	3.0	5.0	88.0	52.3	22.5	76.6	50.4	22.5	6665	46.7	1	409	371	0.34
5/23/96	143	Roosevelt	Hotpoint	CTY14CMDRWH	Automatic	0.0	75	90	7.0	9.0	83.6	45.7	23.0	75.2	44.6	17.9	14235	99.6	1	873	858	1.17
5/29/96	168	Van Dyke II	Sears	2539305396	Automatic	0.0	60	15	5.0	9.0	78.5	39.8	11.4	83.1	51.0	20.8	28600	169.9	1	1488	1418	1.71
5/29/96	168	Van Dyke II	Westinghouse	AGT15ONLW2	Automatic	0.0	70	20	9.0	9.0	78.7	47.8	21.4	80.5	46.4	17.5	16589	98.7	1	865	845	1.21
5/30/96	166	Adams	Westinghouse	MRT15CGAWO	Automatic	0.0	50	10	1.0	7.0	72.0	43.0	18.4	78.2	47.8	26.7	32868	197.9	1	1734	1907	3.06
5/30/96	166	Adams	Westinghouse	WRT15CGAWO	Automatic	0.0	40	5	4.0	7.0	75.0	42.5	12.9	78.4	44.4	13.9	11668	70.1	1	614	644	1.03
6/ 5/96	331	Van Dyke II	Kenmore	571033364	Manual	1.0	60	60	3.0	5.0	78.6	47.4	16.5	78.3	50.2	21.5	28054	84.8	1	743	748	0.96
6/ 5/96	48	Van Dyke II	Kenmore	571033364	Manual	0.8	30	25	0.5	5.0	85.8	46.8	18.1	85.8	46.8	18.1	5060	105.2	0	921	785	1.03
6/ 5/96	333	Van Dyke II	Kenmore	571033364	Manual	0.8	30	25	2.0	5.0	83.6	45.5	15.3	83.6	45.5	15.3	28289	85.0	1	745	668	0.87
6/ 6/96	336	Adams	Hotpoint	CTXY14CHERWH		0.0	50	50	8.0	9.0	79.7	50.1	20.3	76.3	50.4	23.5	46771	139.2	1	1219	1242	1.70
6/ 6/96	336	Adams	Hotpoint	CTA15CKB	Manual	0.5	40	40	6.0	9.0	82.1	51.5	19.3	79.4	48.0	19.1	15103	45.0	1	394	374	0.49
6/ 6/96	336	Adams	Kenmore	60201	Automatic	3.0	40	20	2.0	9.0	81.6	51.1	27.2	78.7	49.1	31.4	47500	141.6	1	1240	1190	1.64
6/ 6/96	336	Adams	Westinghouse	MRT15CNBZO	Automatic	0.0	70	50	5.0	7.0	81.6	52.2	31.7	76.6	47.1	30.6	25600	76.3	1	668	660	1.06
6/ 6/96	336	Adams	Sears	2539305396	Automatic	0.0	60	80	5.0	9.0	81.2	47.9	33.4	78.2	46.5	21.8	62322	185.6	1	1626	1584	1.91
6/ 6/96	335	Bronxdale	Westinghouse	WRT15CGAZO	Automatic	0.0	70	70	3.5	9.0	81.2	56.3	24.3	79.1	47.2	22.1	28768	85.9	1	753	723	1.16
6/ 6/96	336	Bronxdale	Gibson	N/A (Gibson)	Manual	0.5	70	70	5.0	9.0	84.3	50.7	36.5	77.7	42.9	28.3	59079	175.8	1	1540	1447	N/A
6/ 6/96	335	Bronxdale	Westinghouse	MRT15CNCZO	Automatic	0.0	25	20	7.0	7.0	81.2	48.1	16.9	78.1	48.9	28.0	47029	140.4	1	1230	1200	1.92
6/16/96	503	Wald	Whirlpool	ET12PCXWLO	Manual	0.8	40	40	3.0	5.0	83.0	45.6	14.0	86.3	54.5	20.0	47015	93.4	1	818	707	0.80
6/19/96	138	Saratoga Sq	GE	TA11SAB	Manual	0.5	15	10	2.0	9.0	79.7	47.0	29.5	81.0	47.2	29.2	8821	64.0	1	561	537	N/A
6/20/96	143	Adams	Gibson	RT14C1WM	Manual	4.0	75	50	6.0	9.0	78.7	52.3	25.1	83.8	47.4	26.5	29867	209.1	1	1831	1709	1.89
6/20/96	141	Adams	Westinghouse	AGT15ONCWZ	Automatic	0.0	40	40	8.0	9.0	82.9	40.0	22.3	81.8	45.1	23.4	21790	154.6	1	1355	1246	1.79
6/20/96	502	Adams	Kenmore	60201	Manual	0.5	70	30	3.5	5.0	77.0	49.3	22.3	83.6	47.9	22.6	72974	145.3	1	1273	1220	1.68
6/20/96	144	Bronxdale	Hotpoint	CTA12CYC	Manual	1.0	20	60	9.0	9.0	79.4	60.4	12.4	79.9	51.7	16.4	22261	155.0	1	1358	1322	1.35
6/20/96	143	Bronxdale	Whirlpool	ET14DCXRWRO	Manual	0.1	50	50	4.0	5.0	76.0	56.7	32.4	76.6	46.3	18.0	13886	97.1	1	850	913	1.16
6/20/96	143	Bronxdale	GE	TA12STB	Manual	4.0	10	40	4.0	9.0	80.7	42.5	28.3	80.7	37.8	15.5	16648	116.1	1	1017	972	1.53
6/25/96	360	Saratoga Sq	Hotpoint	SSD11CBB	Manual	0.1	90	80	8.0	9.0	84.3	42.7	21.8	83.9	44.4	21.0	43439	120.7	1	1057	932	1.85
6/25/96	341	Saratoga Sq	Westinghouse	WRT15CGA20	Automatic	0.0	30	20	3.5	9.0	84.6	53.9	27.0	84.6	53.9	27.0	42105	123.6	1	1083	916	1.47
6/25/96	359	Saratoga Sq	Roper	RT12DKYWOOO	Automatic	0.0	20	10	3.0	5.0	82.3	43.0	15.1	84.1	48.5	20.7	6880	19.1	1	168	151	0.27
6/25/96	358	Van Dyke I	Kenmore	N/A (Kenmore)	Manual	0.0	40	15	3.5	5.0	83.5	52.1	22.8	82.1	56.9	40.1	22852	63.8	1	558	491	N/A
6/25/96	502	Van Dyke I	Whirlpool	ET14DCXRWRO	Automatic	3.0	60	25	3.0	5.0	86.2	50.1	20.7	86.2	50.1	20.7	64083	127.7	1	1119	933	1.19
6/25/96	358	Van Dyke I	Whirlpool	ET12CXLWRO	Manual	0.0	90	40	4.0	5.0	85.6	41.5	14.9	85.6	41.5	14.9	40161	112.3	1	984	852	1.06
6/26/96	361	Adams	Kenmore	60201	Manual	0.0	60	30	2.0	5.0	84.2	48.4	14.0	84.9	45.6	14.0	50963	141.1	1	1236	1062	1.49
6/26/96	362	Adams	Hotpoint	CTA15CKB	Manual	0.5	75	30	3.0	9.0	81.5	47.4	15.1	83.9	41.6	21.8	41958	116.0	1	1016	926	1.21
6/26/96	362	Adams	Westinghouse	WRT15CGA20	Automatic	0.0	80	90	3.0	9.0	79.4	48.0	25.8	83.1	48.5	25.4	43092	119.2	1	1044	977	1.57
6/26/96	360	Saratoga Sq	Hotpoint	SSD11CBB	Manual	0.3	25	15	6.0	9.0	86.3	51.2	23.1	86.4	54.5	40.7	28891	80.3	1	704	584	1.12
6/26/96	337	Wald	GE	TB14SAB	Manual	0.5	60	60	5.0	9.0	85.6	50.7	18.6	84.9	47.3	14.5	55224	164.0	1	1437	1237	1.16

Audit			Refrigerator Type		Features	Frost	Food Loading		Temp Control		Temperatures (Start)			Temperatures (End)			Raw Usage		I	Annualized Consumption		
Date (-)	Duration (hr)	Site (-)	Manufacturer (-)	Model No. (-)	Defrost (-)	Accum (in)	Refrig. (%)	Freezer (%)	Setting (-)	Scale (-)	Ambient (°F)	Refrig. (°F)	Freezer (°F)	Ambient (°F)	Refrig. (°F)	Freezer (°F)	Energy (Whr)	Watts (W)	(-)	Raw (kWh/yr)	Adjusted (kWh/yr)	Fraction (-)
6/26/96	336	Wald	Westinghouse	MRT15CNCWO		0.0	80	90	2.0	7.0	82.5	47.1	13.2	84.1	49.0	18.1	44581	132.5	1	1161	1040	1.67
7/10/96	167	Saratoga Sq	Roper	RT12VKXDWOO	Automatic	0.0	30	20	5.0	9.0	84.1	45.2	19.3	85.3	49.1	20.7	37675	225.2	1	1973	1709	3.01
7/10/96	167	Saratoga Sq	Hotpoint	SSD11CBB	Manual	0.0	40	60	1.0	9.0	82.8	52.8	35.4	84.7	53.5	32.2	12515	74.8	1	655	561	1.11
7/10/96	165	Van Dyke I	Sears	2539305396	Automatic	0.0	90	90	9.0	9.0	85.7	52.3	32.9	86.2	45.9	15.7	23659	143.1	1	1254	1050	1.27
7/10/96	167	Van Dyke I	Roper	RT14DKYWOOO	Automatic	0.0	70	80	5.0	5.0	83.4	44.3	17.7	83.0	52.9	25.2	21733	130.1	1	1140	1021	1.20
7/11/96	167	Adams	Roper	RT12DKYWOOO	Automatic	0.0	30	30	5.0	5.0	84.8	55.2	8.2	88.4	58.5	7.6	21083	126.0	1	1103	898	1.58
7/11/96	167	Adams	Westinghouse	MRT15CNCWO	Automatic	0.0	50	30	1.0	7.0	82.9	36.4	10.0	87.8	56.5	31.2	20960	125.1	1	1096	938	1.50
7/11/96	122	Adams	Westinghouse	WRT15CGAWO	Automatic	0.0	70	90	-2.0	-3.0	85.6	44.7	30.5	85.6	44.7	0.0	67096	550.0	1	4818	4144	6.64
7/17/96	334	Rutgers	Gibson	RT121WE	Manual	1.0	0	5	9.0	9.0	85.9	41.4	10.5	82.4	42.8	10.7	42466	127.3	1	1115	994	1.06
7/17/96	335	Rutgers	Gibson	RT12C1WE	Manual	0.5	5	5	9.0	9.0	88.1	51.4	14.4	86.2	49.9	11.0	34920	104.3	1	913	747	0.81
7/17/96	334	Rutgers	Gibson	RT121WE	Manual	0.0	70	70	9.0	9.0	86.9	50.1	7.0	79.0	43.7	3.3	52379	156.6	1	1372	1248	1.35
7/17/96	334	Van Dyke I	Westinghouse	RT12CGCWA	Automatic	0.0	60	40	9.0	9.0	85.3	47.5	13.7	78.5	46.3	12.8	42483	127.0	1	1113	1032	1.27
7/17/96	334	Van Dyke I	Westinghouse	WRT15CGAWO	Automatic	0.5	30	30	-3.0	-3.0	88.1	47.5	14.1	78.5	41.5	12.0	47062	140.9	1	1234	1116	1.79
7/17/96	334	Van Dyke I	Westinghouse	RT12OGLW4	Automatic	0.0	70	80	5.0	9.0	85.7	54.3	34.3	79.1	49.7	29.0	28356	84.9	1	744	667	0.82
7/31/96	167	Rutgers	Sears	2539305396	Automatic	0.0	45	30	7.0	9.0	76.6	43.6	24.9	71.3	43.3	23.6	18207	108.9	1	954	1049	1.27
7/31/96	167	Rutgers	Westinghouse	MRT15CNBZ1	Automabc	0.0	45	30	7.0	7.0	76.6	42.6	18.2	76.6	41.9	15.2	14087	84.3	1	738	775	1.24
7/31/96	167	Van Dyke I	Whirlpool	EET122DTWO	Automatic	1.0	60	40	2.5	5.0	83.8	44.4	21.7	84.6	39.7	15.9	17182	102.8	1	901	799	0.74
7/31/96	'167	Van Dyke I	Whirlpool	ET14DCXWLO	Automatic	0.5	15	25	4.0	5.0	80.5	48.2	14.8	83.9	43.9	6.2	17193	102.7	1	900	833	0.99
7/31/96	167	Van Dyke I	Whirlpool	ET14AKXSNO2	Automatic	0.0	65	20	3.0	5.0	79.6	52.5	15.8	83.5	47.7	26.9	28094	168.4	1	1475	1370	1.54
7/31/96	167	Van Dyke I	Westinghouse	MRT15CNCWO	Automatic	0.0	40	30	6.0	7.0	82.0	52.8	26.7	84.3	49.8	19.1	17329	103.6	1	908	806	1.29
8/ 1/96	529	Jackson	Whirlpool	EHT141DTWLO	Automatic	1.5	80	80	5.0	5.0	83.1	48.7	31.1	87.1	49.4	27.5	95195	179.9	1	1576	1335	1.44
8/ 1/96	333	Jackson	Westinghouse	RT143SLWO	Automatic	0.0	65	25	8.0	9.0	100.0	0.0	0.0	100.0	0.0	0.0	22930	68.8	0	602	474	0.57
8/ 1/96	524	Jackson	Hotpoint	CTXY14PGLWH	Automatic	0.0	60	90	6.0	9.0	81.6	45.4	23.7	83.6	45.2	21.0	65642	125.3	1	1097	1001	1.37
8/ 1/96	505	Jackson	Westinhouse	RT143SLWO		0.0	75	60	7.5	9.0	81.7	43.4	23.0	86.5	48.7	17.9	72855	144.2	1	1263	1113	1.34
8/ 7/96	358	Van Dyke I	Westinghouse	WRT15CGAWO	Automatic	0.0	50	50	2.0	9.0	85.4	49.0	27.5	82.5	56.0	30.6	28578	79.8	1	699	603	0.97
8/ 7/96	358	Van Dyke I	Hotpoint	CTH14XYLLWH	Automatic	0.0	20	90	6.0	9.0	83.9	45.3	23.7	82.8	38.2	20.7	41973	117.2	0	1027	927	1.86
8/ 7/96	358	Van Dyke I	Whirlpool	EET122DT	Manual	0.5	70	70	3.0	5.0	78.4	46.3	15.9	75.0	37.3	16.6	47811	133.5	1	1170	1226	1.13
8/ 7/96	360	Van Dyke I	Hotpoint	CTXY14CMERW	Automatic	0.0	65	25	7.0	9.0	82.0	46.9	16.4	80.2	46.5	20.7	27723	77.1	1	675	637	0.87
8/ 8/96	334	Jackson	Roper	RT12DKX13WOO	Automatic	0.0	50	10	4.0	5.0	83.6	56.1	31.2	80.3	44.4	9.1	27295	68.7	1	602	553	0.98
8/ 8/96	456	Jackson	Roper	RT14DCXVW10	Automatic	0.0	85	90	3.0	5.0	85.5	48.8	20.3	85.7	49.2	22.8	99269	217.9	1	1909	1617	1.94
8/23/96	453	Jackson	Whirlpool	EHT1410TWRO	Manual	0.5	50	25	3.0	5.0	83.1	50.9	34.6	84.1	47.7	23.1	57418	126.8	1	1111	976	1.05
8/23/96	453	Jackson	Hotpoint	CTXY14CPGRW	Automatic	0.0	70	40	9.0	9.0	90.0	45.9	19.5	85.6	48.4	19.7	66009	145.7	1	1276	1039	1.42
8/23/96	455	Jackson	Whirlpool	EHT1410TWRO	Manual	1.0	75	90	4.0	5.0	84.7	52.9	34.7	85.7	48.8	31.4	73684	162.0	1	1419	1186	1.28
8/23/96	449	Jackson	Whirlpool	EET122TWRO	Manual	0.0	60	40	3.0	5.0	87.1	54.3	35.9	83.9	49.6	23.6	41692	92.8	1	813	673	0.62
8/23/96	450	Jackson	Westinghouse	WRT15CGAZO	Automatic	0.0	50	90	9.0	9.0	87.1	49.2	30.6	83.1	40.0	17.7	61962	137.7	1	1206	1040	1.67
8/23/96	453	Jackson	Westinghouse	WRT15CGAZO	Automabc	0.0	50	25	8.0	9.0	81.6	45.4	10.2	83.1	44.3	17.0	61308	135.3	1	1185	1092	1.75
8/23/96	455	Jackson	Roper	RT12DCYA00	Automatic	0.0	90	90	3.0	5.0	84.6	51.5	16.3	83.2	52.1	15.4	38118	79.3	1	695	609	0.78
8/23/96	458	Jackson	Whirlpool	EET122DTWRO	Manual	1.0	60	40	4.5	5.0	86.8	41.5	20.9	82.3	50.6	23.9	71655	156.5	1	1371	1193	1.10
8/23/96	446	Jackson	Westinghouse	RT143SCW0	Automatic	0.0	75	80	9.0	9.0	84.2	47.0	22.6	82.5	45.9	26.3	56743	127.2	1	1114	994	1.20
8/23/96	454	Jackson	Roper	RT14DCXVW10	Automatic	0.0	60	25	5.0	5.0	84.5	47.0	19.2	84.8	44.7	18.0	67210	147.9	1	1296	1133	1.36

Audit			Refrigerator Type		Features	Frost	Food Loading		Temp Control		Temperatures (Start)			Temperatures (End)			Raw Usage		I	Annualized Consumption		
Date (-)	Duration (hr)	Site (-)	Manufacturer (-)	Model No. (-)	Defrost (-)	Accum (In)	Refrig. (%)	Freezer (%)	Setting (-)	Scale (-)	Ambient (°F)	Refrig. (°F)	Freezer (°F)	Ambient (°F)	Refrig. (°F)	Freezer (°F)	Energy (Whr)	Watts (W)	(-)	Raw (kWh/yr)	Adjusted (kWh/yr)	Fraction (-)
8/23/96	458	Jackson	Hotpoint	CTA12CBC	Manual	0.3	90	50	9.0	9.0	84.5	40.3	13.6	85.7	45.8	15.7	91880	200.6	1	1757	1538	1.59
8/23/96	454	Jackson	Whirlpool	EHT1410TWRO		1.0	65	65	4.0	5.0	84.1	51.4	18.9	86.2	42.0	22.0	59150	130.3	1	1142	982	1.06
9/11/96	162	Moore	Westinghouse	MRT15CNCWO	Automatic	0.5	40	25	7.0	7.0	86.6	51.8	15.8	77.2	39.7	11.1	16627	102.5	1	898	834	1.34
9/11/96	162	Moore	Whirlpool	EHT141DTWRO	Automatic	1.0	90	75	2.5	5.0	82.9	51.2	27.2	76.7	45.3	34.7	24153	148.7	1	1303	1264	1.37
9/11/96	162	Moore	Whirlpool	EHT141DTWRO	Automatic	1.0	90	75	2.5	5.0	86.8	51.3	24.8	75.8	44.4	35.9	20417	125.7	1	1101	1027	1.11
9/11/96	162	Moore	Whirlpool	EHT141DTWRO	Automatic	0.3	40	25	2.0	5.0	84.5	55.7	23.5	74.3	46.2	26.5	21414	131.9	1	1155	1133	1.22
9/12/96	143	Moore	Hotpoint	SSD12CVC	Manual	2.0	15	10	1.0	9.0	73.6	29.5	15.4	73.6	29.5	15.4	8669	60.5	1	530	587	1.00
9/12/96	145	Moore	Westinghouse	MRT15CNCWO	Automatic	0.0	40	15	1.0	7.0	82.6	53.2	20.3	75.3	50.0	20.4	9107	62.8	1	550	546	0.88
9/12/96	146	Moore	Whirlpool	EET122DT	Manual	0.3	40	25	2.0	5.0	80.3	47.7	19.9	76.1	47.0	24.2	16853	115.8	1	1015	1028	0.95
9/12/96	145	Moore	GE	TB14SVB	Manual	0.5	60	20	9.0	9.0	80.1	51.8	0.0	74.6	49.3	32.2	39152	270.9	1	2374	2457	2.35
9/12/96	144	Moore	Westinghouse	RT141GLWA	Automatic	0.0	60	40	8.0	9.0	80.1	52.8	22.0	79.9	49.1	19.1	23841	166.0	1	1454	1404	1.70
9/12/96	32	Moore	Whirlpool	EHT141DTWRO	Automatic	1.0	70	80	3.5	5.0	78.3	42.0	6.0	78.3	42.0	6.0	3304	103.3	0	904	912	0.99
9/12/96	144	Moore	Westinghouse	MRT15CNCWO	Automatic	0.0	80	25	1.0	7.0	79.5	48.7	25.1	74.6	48.0	24.3	13632	94.7	1	829	868	1.39
9/18/96	330	Coney Island	Hotpoint	CTA13CGE	Manual	0.5	50	25	6.0	9.0	80.2	39.9	17.2	77.9	43.6	22.1	33650	102.1	1	894	887	1.20
9/19/96	313	Coney Island	Hotpoint	CTA13CJC	Manual	2.0	40	40	4.0	9.0	77.6	49.3	22.2	78.1	43.7	8.7	41620	133.0	1	1165	1189	1.61
9/19/96	314	Coney Island	Westinghouse	WRT15CGAZO	Automatic	0.0	50	20	6.0	7.0	76.8	41.9	13.0	77.1	45.4	19.5	34468	109.8	1	962	1003	1.61
9/19/96	185	Coney Island	Hotpoint	CT13CJC	Manual	1.0	60	60	4.0	9.0	77.2	40.5	25.1	77.2	40.5	20.1	16767	90.6	1	794	822	1.11
9/19/96	127	Coney Island	Gibson	RT12C1WM	Manual	1.0	60	20	6.0	9.0	72.7	48.2	24.0	79.0	49.5	26.9	11488	90.2	1	791	858	1.04
9/19/96	307	Coney Island	Gibson	RD14C1WMGA	Manual	0.3	15	5	8.0	9.0	75.3	60.2	20.4	74.1	67.2	44.0	37330	121.6	1	1065	1276	1.41
9/19/96	339	Coney Island	Hotpoint	CTXY14CPJLWH	Automatic	0.0	50	25	6.0	9.0	78.1	46.2	25.7	78.6	47.5	20.7	47072	138.8	1	1216	1227	1.67
9/19/96	314	Coney Island	Hotpoint	CTA13CKB	Manual	2.0	75	90	2.0	9.0	75.9	47.3	28.0	74.9	48.0	28.0	25423	81.0	1	709	778	1.06
9/19/96	313	Coney Island	Hotpoint	CTA13CKB	Manual	2.5	50	90	8.0	9.0	77.3	46.2	20.1	74.6	47.5	22.4	31096	99.4	1	870	935	1.27
9/19/96	335	Coney Island	Hotpoint	CTA13CJC	Manual	0.5	70	40	5.0	9.0	77.0	46.1	29.0	73.5	48.1	22.8	28227	84.3	1	738	811	1.10
10/ 2/96	190	Coney Island	Hotpoint	CTA13CJB	Manual	0.3	80	25	7.0	7.0	76.4	50.0	15.1	74.7	43.3	22.1	19926	104.8	1	918	994	1.35
10/ 2/96	168	Coney Island	Hotpoint	CTA13CKB	Manual	0.3	70	40	8.0	9.0	78.8	41.9	5.7	76.9	45.4	22.4	20833	123.7	1	1084	1105	1.50
10/ 2/96	170	Coney Island	Kenmore	2538604091	Automatic	0.0	75	50	8.0	9.0	76.9	48.7	33.6	73.7	47.0	21.8	8029	47.2	1	414	456	0.55
10/ 2/96	143	Coney Island	Gibson	RD12C1WMGA	Manual	3.0	40	25	9.0	9.0	75.2	39.9	23.5	74.6	40.8	26.6	19125	133.9	0	1173	1289	1.56
10/ 2/96	144	Coney Island	Hotpoint	CTA13CKB	Manual	3.0	25	25	4.0	9.0	77.7	49.4	22.7	75.7	49.0	23.3	13723	95.4	1	836	883	1.20
10/ 3/96	138	Coney Isaind	Westinghouse	ATG15ONLW2	Automatic	0.0	70	20	9.0	9.0	75.7	51.7	21.5	75.5	45.2	17.4	15629	113.2	1	992	1081	1.55
10/ 3/96	144	Coney Island	Hotpoint	CTA13CKB		3.0	50	40	3.0	9.0	75.4	47.3	23.4	74.8	46.4	24.0	12184	84.8	1	743	818	1.11
10/ 3/96	148	Coney Island	Hotpoint	CTA13CKB	Manual	3.0	60	70	9.0	9.0	74.3	38.7	-3.0	74.3	38.7	-3.0	10856	73.5	1	644	702	0.95
10/ 3/96	143	Coney Island	Gibson	RT14C1WMGA	Manual	2.0	50	60	9.0	9.0	81.3	35.7	14.7	79.0	44.0	20.2	25080	175.4	1	1537	1489	1.65
10/ 3/96	148	Coney Island	Hotpoint	CTA13CKB	Manual	0.5	40	5	9.0	9.0	78.3	37.9	1.9	78.3	37.9	1.9	7431	50.3	0	441	444	0.60
10/ 3/96	21	Coney Island	Hotpoint	CTA13CJB	Manual	1.5	75	50	4.0	9.0	78.7	44.2	24.0	77.0	41.0	21.0	1688	80.8	0	708	722	0.98
10/ 8/96	20	Coney Island	Westinghouse	RT14BNCWC	Automatic	0.0	60	60	9.0	9.0	77.9	46.6	24.0	76.9	48.1	26.9	3003	151.8	0	1330	1377	1.66
10/ 8/96	20	Coney Island	Roper	RT14DCXVW01	Automatic	0.0	80	90	2.0	5.0	74.1	46.8	17.9	77.3	50.5	25.1	2924	144.9	0	1269	1376	1.55
10/ 8/96	19	Coney Island	Hotpoint	CTX14MCRWH	Automatic	0.0	60	60	2.0	9.0	74.4	48.2	29.5	75.9	49.0	23.5	1650	88.1	0	772	854	1.16
10/ 8/96	19	Coney Island	Sears	2539305316	Automatic	0.0	60	60	7.0	9.0	76.3	44.8	16.2	77.7	44.0	15.5	2967	156.8	0	1374	1430	1.73
10/ 8/96	20	Coney Island	Roper	RT12DKXBWOO	Automatic	0.0	50	50	5.0	5.0	76.2	42.3	19.8	79.2	44.0	20.2	2281	115.0	0	1007	1032	1.82
10/ 9/96	19	Coney Island	Gibson	RD12C1WMGA	Manual	0.8	90	90	9.0	9.0	78.5	48.3	21.2	78.2	54.2	33.1	3109	164.4	0	1440	1455	1.77

Audit			Refrigerator Type		Features	Frost	Food Loading		Temp Control		Temperatures (Start)			Temperatures (End)			Raw Usage		I	Annualized Consumption		
Date (-)	Duration (hr)	Site (-)	Manufacturer (-)	Model No. (-)	Defrost (-)	Accum (In)	Refrig. (%)	Freezer (%)	Setting (-)	Scale (-)	Ambient (°F)	Refrig. (°F)	Freezer (°F)	Ambient (°F)	Refrig. (°F)	Freezer (°F)	Energy (Whr)	Watts (W)	(-)	Raw (kWh/yr)	Adjusted (kWh/yr)	Fraction (-)
10/ 9/96	22	Coney island	Gibson	RD12C1WMGA	Manual	0.0	50	60	7.0	9.0	75.1	48.2	36.1	75.6	50.7	35.0	2176	99.5	0	872	971	1.18
10/ 9/96	22	Coney Island	Westinghouse	RT14SCWO	Automatic	0.0	70	90	9.0	9.0	73.8	42.5	25.3	69.3	44.6	24.8	1837	83.7	0	733	891	N/A
10/ 9/96	23	Coney Island	Gibson	RT12C1WMGA	Manual	1.0	40	50	3.0	9.0	74.5	54.3	25.4	74.9	49.0	27.0	2672	115.8	0	1014	1151	1.40
10/ 9/96	23	Coney Island	Sears	2539305010	Automatic	0.0	65	40	6.0	9.0	71.8	48.6	27.7	73.7	48.9	24.4	2835	121.8	0	1067	1270	1.53
10/ 9/96	22	Coney Island	Gibson	RD12C1WMGA	Manual	0.0	15	50	3.0	9.0	74.8	52.4	23.6	75.7	51.1	25.3	1932	87.6	0	767	853	1.04
10/ 9/96	22	Coney Island	Gibson	RD12C1WMGA	Manual	0.0	60	30	4.0	9.0	77.1	51.2	29.0	76.0	49.5	24.8	2381	106.9	0	937	999	1.21
10/ 9/96	23	Coney Island	Gibson	RD12C1WMGA	Manual	0.0	50	25	1.0	9.0	73.5	54.2	32.5	74.2	52.0	29.8	1328	57.4	0	503	595	0.72
10/10/96	291	Coney Isalnd	GE	TBF18SMO	Automatic	0.0	70	80	6.5	9.0	76.8	50.8	20.9	76.8	50.8	20.9	161001	553.2	1	4846	5105	2.74
10/10/96	167	Coney Isalnd	Gibson	RT14C1WM	Automatic	1.0	75	80	8.0	9.0	80.3	47.8	32.8	80.3	39.9	22.7	19666	117.9	1	1033	993	1.10
10/10/96	166	Coney Isalnd	Westinghouse	WRT15CGAWO	Automatic	0.0	75	60	7.0	7.0	78.2	46.9	25.6	75.7	43.9	20.2	13702	82.3	1	721	755	1.21
10/10/96	166	Coney Isand	Gibson	RD12C1WMGA	Manual	1.0	15	15	5.0	9.0	78.6	51.0	24.7	76.6	52.2	39.7	15864	95.5	1	837	867	1.05
10/10/96	166	Coney Island	Gibson	RD14C1WMGA	Manual	2.0	60	80	6.0	9.0	74.5	46.8	22.8	76.8	43.2	20.4	21097	127.1	1	1114	1204	1.33
10/10/96	167	Coney Island	Gibson	RD12C1WMGA	Manual	1.3	85	90	7.0	9.0	76.8	50.9	26.0	78.1	48.9	18.5	15413	92.5	1	810	839	1.02
10/10/96	166	Coney Island	Westinghouse	MRT15CNBWI	Automatic	0.0	70	60	6.0	7.0	76.9	47.4	25.4	76.0	41.2	19.3	13648	82.1	1	719	761	1.22
10/10/96	166	Coney Island	Gibson	RD12C1WMGA	Manual	0.0	60	60	6.0	9.0	77.2	51.0	25.4	76.4	50.2	28.2	12694	76.3	1	669	706	0.86
10/10/96	167	Coney Island	Whirlpool	EET121DT	Manual	1.0	60	75	5.0	5.0	79.2	47.6	17.7	78.9	46.8	19.5	20952	125.6	1	1100	1091	1.01
05/22/96	216	Yonkers	GE	CTA12CCB	0.0	0.0	0	0	0.0	0.0							17650	81.8	0	717		
05/22/96	215	Yonkers	GE	CTA14CBS	0.0	0.0	0	0	0.0	0.0							25720	119.4	0	1046		
05/22/96	215	Yonkers	GE	CTA15CGE	0.0	0.0	0	0	0.0	0.0							28030	130.1	0	1139		
05/22/96	216	Yonkers	GE	CTA15	0.0	0.0	0	0	0.0	0.0							22520	104.5	0	915		
05/22/96	215	Yonkers	GE	CTA15CGE	0.0	0.0	0	0	0.0	0.0							26090	121.1	0	1061		
05/22/96	216	Yonkers	GE	CTA14CBS	0.0	0.0	0	0	0.0	0.0							25540	118.5	0	1038		
05/22/96	215	Yonkers	GE	CTA14CBD	0.0	0.0	0	0	0.0	0.0							26310	122.2	0	1070		
05/22/96	215	Yonkers	GE	SSD14CGB	0.0	0.0	0	0	0.0	0.0							21490	99.8	0	874		
05/22/96	215	Yonkers	GE	CTA14CBD	0.0	0.0	0	0	0.0	0.0							32090	149.0	0	1305		
05/22/96	215	Yonkers	GE	CTA12CCB	0.0	0.0	0	0	0.0	0.0							30770	142.8	0	1251		
05/22/96	215	Yonkers	GE	CTA14CFB	0.0	0.0	0	0	0.0	0.0							32550	151.1	0	1324		
05/22/96	215	Yonkers	GE	CTA14CFB	0.0	0.0	0	0	0.0	0.0							23680	109.9	0	963		
05/22/96	215	Yonkers	GE	CTA14CFB	0.0	0.0	0	0	0.0	0.0							34280	159.2	0	1395		
05/22/96	215	Yonkers	GE	CTA15CGE	0.0	0.0	0	0	0.0	0.0							24370	113.4	0	994		
09/12/96	314	Tuckahoe	Kenmore	2538632313	0.0	0.0	0	0	0.0	0.0	73.2	51.1	13.7	73.2	51.1	13.7	40790	130.0	0	1139		
09/12/96	314	Tuckahoe	Kenmore	2538632393	0.0	0.0	0	0	0.0	0.0	80.4	53.7	25.1	80.4	53.7	25.1	36410	115.9	0	1016		
09/12/96	314	Tuckahoe	Kenmore	2538632312	0.0	0.0	0	0	0.0	0.0	82.9	50.3	14.0	82.9	50.3	14.0	32090	102.2	0	896		
09/12/96	314	Tuckahoe	Kenmore	2538632393	0.0	0.0	0	0	0.0	0.0	79.3	48.6	20.4	79.3	48.6	20.4	29740	94.7	0	830		
09/12/96	314	Tuckahoe	Kenmore	2538632313	0.0	0.0	0	0	0.0	0.0	82.9	48.3	12.4	82.9	48.3	12.4	25190	80.3	0	703		
09/12/96	314	Tuckahoe	Kenmore	2538632393	0.0	0.0	0	0	0.0	0.0	83.2	47.2	12.1	83.2	47.2	12.1	28800	91.8	0	804		
09/12/96	314	Tuckahoe	Kenmore	2538632393	0.0	0.0	0	0	0.0	0.0	80.7	56.0	32.4	80.7	56.0	32.4	32390	103.2	0	904		
09/12/96	314	Tuckahoe	Kenmore	2538632313	0.0	0.0	0	0	0.0	0.0	79.8	50.4	18.6	79.8	50.4	18.6	27390	87.3	0	765		
09/12/96	313	Tuckahoe	Kenmore	2538632392	0.0	0.0	0	0	0.0	0.0	84.3	51.9	15.9	84.3	51.9	15.9	10590	33 9	0	297		
09/12/96	314	Tuckahoe	Kenmore	2538632393	0 0	0.0	0	0	0.0	0.0	79.3	48.5	11.5	79.3	48.5	11.5	38400	122.4	0	1072		

Audit			Refrigerator Type		Features	Frost	Food Loading		Temp Control		Temperatures (Start)			Temperatures (End)			Raw Usage		I	Annualized Consumption		
Date (-)	Duration (hr)	Site (-)	Manufacturer (-)	Model No. (-)	Defrost (-)	Accum (in)	Refrig. (%)	Freezer (%)	Setting (-)	Scale (-)	Ambient (°F)	Refrig. (°F)	Freezer (°F)	Ambient (°F)	Refrig. (°F)	Freezer (°F)	Energy (Whr)	Watts (W)	(-)	Raw (kWh/yr)	Adjusted (kWh/yr)	Fraction (-)
09/12/96	314	Tuckahoe	Kenmore	2537692283	0.0	0.0	0	0	0.0	0.0	79.6	41.3	20.2	79.6	41.3	20.2	37400	119.2	0	1044		
09/12/96	314	Tuckahoe	Kenmore	2538632393	0.0	0.0	0	0	0.0	0.0	83.9	48.0	6.5	83.9	48.0	6.5	25330	80.7	0	707		
09/12/96	314	Tuckahoe	Kenmore	3639652211	0.0	0.0	0	0	0.0	0.0	75.0	58.9	18.8	75.0	58.9	18.8	13750	43.8	0	384		
05/10/96	245	Tuckahoe	Kenmore	2539307210	0.0	0.0	0	0	0.0	0.0							28170	115.1	0	1008		
05/10/96	245	Tuckahoe	Kenmore	2539658010	0.0	0.0	0	0	0.0	0.0							23750	97.0	0	850		
05/10/96	504	Tuckahoe	Kenmore	2538646210	0.0	0.0	0	0	0.0	0.0							74480	147.7	0	1294		
05/10/96	245	Tuckahoe	Kenmore	2538646210	0.0	0.0	0	0	0.0	0.0							25610	104.7	0	917		
05/10/96	245	Tuckahoe	Kenmore	2538357210	0.0	0.0	0	0	0.0	0.0							32650	133.5	0	1169		
05/10/96	244	Tuckahoe	Kenmore	2538632393	0.0	0.0	0	0	0.0	0.0							24170	99.0	0	867		
05/10/96	244	Tuckahoe	Kenmore	2538632313	0.0	0.0	0	0	0.0	0.0							29080	119.3	0	1045		
05/10/96	244	Tuckahoe	Kenmore	2583632312	0.0	0.0	0	0	0.0	0.0							23370	95.9	0	840		
05/10/96	244	Tuckahoe	Kenmore	2538632313	0.0	0.0	0	0	0.0	0.0							21980	90.2	0	790		
05/10/96	244	Tuckahoe	Kenmore	2538632313	0.0	0.0	0	0	0.0	0.0							33820	138.9	0	1217		
05/10/96	243	Tuckahoe	Kenmore	2538632393	0.0	0.0	0	0	0.0	0.0							24690	101.4	0	889		
05/10/96	243	Tuckahoe	Kenmore	2538632313	0.0	0.0	0	0	0.0	0.0							30170	123.9	0	1086		
05/10/96	243	Tuckahoe	Kenmore	2583632312	0.0	0.0	0	0	0.0	0.0							28030	115.2	0	1009		
05/10/96	243	Tuckahoe	Kenmore	2538632393	0.0	0.0	0	0	0.0	0.0							30760	126.4	0	1107		
05/10/96	243	Tuckahoe	Kenmore	2538632393	0.0	0.0	0	0	0.0	0.0							24750	101.7	0	891		
1/26/96	143	Edenwald	Hotpoint	CTH14CYXLLWH	Automatic	0.0	50	70	5.0	9.0	75.9	41.7	17.9	76.9	43.8	14.4	5807	48.5	0	425	448	0.90
2/1/96	162	Edenwald	Hotpoint	CTH14CYXLRWH	Automatic	0.0	60	40	5.0	9.0	64.0	40.4	7.8	74.6	42.7	18.6	12772	78.8	0	690	869	1.74
2/2/96	154	Edenwald	Hotpoint	CTH14CYXLLWH	Automatic	0.0	40	60	5.0	9.0	74.5	49.5	20.2	77.9	43.8	12.7	8808	57.2	0	501	534	1.07
3/1/96	166	Mott Haven	Hotpoint	CTH14CYXLRWH	Automatic	0.0	70	40	5.0	9.0	74.0	40.0	6.0	77.1	49.3	14.7	14294	85.9	0	752	810	1.62
3/1/96	167	Mott Haven	Hotpoint	CTH14CYXLRWH	Automatic	0.0	60	90	5.0	9.0	77.0	48.0	17.0	77.8	48.5	24.7	16130	96.7	0	847	877	1.76
3/1/96	167	Mott Haven	Hotpoint	CTH14CYXLRWH	Automatic	0.0	20	60	5.0	9.0	69.0	53.0	17.0	75.4	40.9	16.1	17288	103.8	0	909	1062	2.17
3/1/96	167	Mott Haven	Hotpoint	CTH14CYXLRWH	Automatic	0.0	25	0	9.0	9.0	74.0	42.0	6.0	77.1	51.7	28.6	19628	117.5	0	1030	1116	2.24
3/1/96	167	Mott Haven	Hotpoint	CTH14CYXLRWH	Automatic	0.0	20	20	5.0	9.0	73.0	35.0	10.0	74.6	44.1	14.5	12990	77.8	0	681	760	1.52
3/1/96	167	Mott Haven	Hotpoint	CTH14CYXLRWH	Automatic	0.0	20	40	6.0	9.0	83.0	40.0	22.0	79.9	47.7	35.9	11144	66.7	0	584	546	1.09
3/1/96	165	Mott Haven	Hotpoint	CTH14CYXLRWH	Automatic	0.0	70	70	5.0	9.0	77.0	40.0	4.0	75.6	48.1	22.5	20730	125.4	0	1099	1162	2.33
3/1/96	166	Mott Haven	Hotpoint	CTH14CYXLRWH	Automatic	0.0	70	50	2.0	9.0	76.0	45.0	17.0	73.2	47.2	27.3	8770	52.9	1	464	517	1.04
3/8/96	341	Mott Haven	Hotpoint	CTH14CYXLRWH	Automatic	0.0	20	40	5.0	9.0	81.3	50.7	23.6	78.4	49.7	17.6	27725	81.4	0	713	692	1.39
3/8/96	341	Mott Haven	Hotpoint	CTH14CYXLRWH	Automatic	0.0	30	70	5.0	9.0	74.7	47.7	21.4	76.4	46.2	31.2	28594	83.9	0	735	802	1.61
3/8/96	341	Mott Haven	Hotpoint	CTH14CYXLRWH	Automatic	0.0	50	70	5.0	9.0	84.7	50.7	26.3	81.0	48.7	18.0	24458	71.8	0	629	566	1.13
3/8/96	341	Mott Haven	Hotpoint	CTH14CYXLRWH	Automatic	0.0	70	25	3.0	9.0	74.9	49.5	24.8	78.9	51.8	21.9	27204	79.8	0	699	736	1.48
3/22/96	143	Gompers	Hotpoint	CTH14CYXLRWH	Automatic	0.0	70	60	5.0	9.0	77.9	49.3	15.8	82.0	48.2	21.0	14110	98.6	0	864	837	1.68
3/22/96	143	Gompers	Hotpoint	CTH14CYXLRWH	Automatic	0.0			5.0	9.0	72.6	46.9	17.0	76.0	45.3	15.8	11440	79.8	0	699	762	1.57
3/22/96	143	Gompers	Hotpoint	CTH14CYXLRWH	Automatic	0.0	50	10	3.0	9.0	75.6	48.4	19.3	74.9	48.1	16.5	7190	50.1	0	439	481	0.96
3/22/96	143	Gompers	Hotpoint	CTH14CYXLRWH	Automatic	0.0	60	20	5.0	9.0	75.4	48.3	21.2	76.6	49.3	22.3	10631	74.2	0	650	699	1.40
3/22/96	327	Gompers	Hotpoint	CTH14CYXLRWH	Automatic	0.0	60	20	5.0	9.0	75.4	49.3	22.3	75.4	49.3	22.3	21312	65.3	0	572	627	1.26
3/22/96	143	Gompers	Hotpoint	CTH14CYXLRWH	Automatic	0.0	60	40	5.0	9.0	64.5	43.0	9.9	67.0	48.7	16.7	5219	36.4	0	319	458	0.92
3/22/96	138	Mott Haven	Hotpoint	CTH14CYXLRWH	Automatic	0.0	20	40	2.0	9.0	78.7	50.3	20.7	78.7	50.3	20.7	8398	60.9	1	534	534	1.07

Audit			Refrigerator Type		Features	Frost	Food Loading		Temp Control		Temperatures (Start)			Temperatures (End)			Raw Usage		I	Annualized Consumption		
Date (-)	Duration (hr)	Site (-)	Manufacturer (-)	Model No. (-)	Defrost (-)	Accum (in)	Refrig. (%)	Freezer (%)	Setting (-)	Scale (-)	Ambient (°F)	Refrig. (°F)	Freezer (°F)	Ambient (°F)	Refrig. (°F)	Freezer (°F)	Energy (Whr)	Watts (W)	(-)	Raw (kWh/yr)	Adjusted (kWh/yr)	Fraction (-)
3/22/96	138	Mott Haven	Hotpoint	CTH14CYXLRWH	Automatic	0.0	30	70	2.0	9.0	76.4	47.1	21.2	74.5	57.5	19.9	5826	42.3	1	370	407	0.82
3/22/96	138	Mott Haven	Hotpoint	CTH14CYXLRWH	Automatic	0.0	50	70	2.0	9.0	81.0	48.7	18.0	74.9	50.3	17.5	6789	49.3	1	432	440	0.88
3/22/96	138	Mott Haven	Hotpoint	CTH14CYXLRWH	Automatic	0.0	70	25	3.0	9.0	78.9	51.8	21.9	76.0	49.2	19.7	10615	77.0	0	675	698	1.40
3/28/96	339	Gompers	Hotpoint	CTH14CYXLRWH	Automatic	0.0	70	60	5.0	9.0	82.0	48.2	21.0	83.4	46.9	19.9	33999	100.2	0	878	797	1.60
3/28/96	339	Gompers	Hotpoint	CTH14CYXLRWH	Automatic	0.0			2.0	9.0	76.0	45.3	15.8	74.2	47.4	22.2	26000	76.7	1	672	738	1.48
3/28/96	985	Gompers	Hotpoint	CTH14CYXLRWH	Automatic	0.0	50	10	3.0	9.0	74.9	48.1	16.5	70.7	49.1	19.3	63046	64.0	0	561	660	1.32
4/11/96	644	Gompers	Hotpoint	CTH14CYXLRWH	Automatic	0.0	70	90	2.0	9.0	78.0	47.8	17.2	76.3	48.4	13.6	52328	81.3	1	712	740	1.48
4/11/96	645	Gompers	Hotpoint	CTH14CYXLRWH	Automatic	0.0	70	60	5.0	9.0	83.4	46.9	19.9	73.5	46.3	15.3	58949	91.4	0	801	806	1.61
4/11/96	644	Gompers	Hotpoint	CTH14CYXLRWH	Automatic	0.0	40	40	2.0	9.0	72.2	49.2	15.7	70.0	51.2	47.3	30378	47.2	1	413	532	1.07
4/11/96	645	Morris	Hotpoint	CTH14CYXLRWH	Automatic	0.0	50	40	3.0	9.0	80.2	40.6	12.1	86.2	51.2	20.0	41234	63.9	0	560	505	1.01
4/11/96	644	Morris	Hotpoint	CTH14CYXLRWH	Automatic	0.0	40	60	2.0	9.0	78.6	54.3	16.2	80.5	53.7	24.6	44008	68.3	1	598	584	1.17
4/11/96	884	Morris	Hotpoint	CTH14CYXLRWH	Automatic	0.0	5	0	2.0	9.0	75.5	43.0	17.7	79.8	53.3	23.7	38306	43.3	1	379	390	0.78
5/22/96	188	Fulton	Hotpoint	CTH14CYXLRWH	Automatic	0.0	40	40	6.0	9.0	80.0	51.9	18.6	72.2	43.8	22.6	19616	104.3	0	913	979	1.96
5/22/96	188	Fulton	Hotpoint	CTH14CYXLRWH	Automatic	0.0	10	2	5.0	9.0	74.3	43.2	19.7	72.1	47.1	19.1	10122	53.8	0	472	544	1.09
5/22/96	340	Fulton	Hotpoint	CTH14CYXLRWH	Automatic	0.0	35	65	4.0	9.0	81.8	46.5	21.5	80.6	50.7	17.9	15975	47.0	0	412	387	0.78
5/22/96	165	Fulton	Hotpoint	CTH14CYXLRWH	Automatic	0.0	70	90	2.0	9.0	79.1	54.1	28.3	71.5	43.2	16.5	12316	74.7	1	654	719	1.44
5/22/96	190	Fulton	Hotpoint	CTH14CYXLRWH	Automatic	0.0	40	20	2.0	9.0	81.1	47.0	23.4	72.2	51.0	23.2	10590	55.7	1	488	516	1.03
5/23/96	165	Fulton	Hotpoint	CTH14CYXLRWH	Automatic	0.0	90	40	3.5	9.0	78.5	63.3	43.3	72.9	49.3	21.0	13634	82.8	0	726	808	1.62
5/23/96	164	Fulton	Hotpoint	CTH14CYXLRWH	Automatic	0.0	25	5	2.0	9.0	76.1	51.3	19.9	71.0	45.6	19.7	9239	56.5	1	495	571	1.14
5/29/96	506	Tompkins	Hotpoint	CTH14CYXLRWH		0.0	50	50	2.0	9.0	78.1	55.4	30.2	79.6	48.6	23.4	35382	69.9	1	612	609	1.22
5/29/96	509	Tompkins	Hotpoint	CTH14CYXLRWH	Automatic	0.0	50	30	5.0	9.0	77.0	64.5	46.8	79.2	50.8	24.8	60131	118.1	0	1034	1057	2.12
5/29/96	510	Tompkins	Hotpoint	CTH14CYXLRWH	Automatic	0.0	50	5	2.0	9.0	76.9	43.3	13.4	83.3	52.8	24.1	38290	75.1	1	658	635	1.27
5/30/96	143	Fulton	Hotpoint	CTH14CYXLRWH	Automatic	0.0	40	40	5.0	9.0	74.1	36.6	17.2	74.1	36.6	5.9	7658	53.4	0	467	515	1.03
5/30/96	36	Fulton	Hotpoint	CTH14CYXLRWH	Automatic	0.0	25	25	2.0	5.0	71.9	38.0	3.5	71.9	38.0	3.5	1801	49.3	0	432	499	1.00
5/30/96	22	Fulton	Hotpoint	CTH14CYXLRWH	Automatic	0.0	25	25	3.5	9.0	74.1	38.7	3.4	74.1	38.7	3.4	1294	58.2	0	509	561	1.12
6/19/96	142	Roosevelt	Hotpoint	CTH14CYXLRWH	Automatic	0.0	25	35	2.0	9.0	81.4	42.1	21.0	85.7	50.7	26.5	9661	67.8	1	594	529	1.06
6/19/96	143	Roosevelt	Hotpoint	CTH14CYXLRWH		0.0	40	40	3.0	9.0	82.8	50.4	31.7	84.5	46.3	18.8	9380	65.6	0	575	507	1.02
7/11/96	167	Bronxdale	Hotpoint	CTH14CYXLLWH	Automatic	0.0	20	20	2.0	9.0	81.4	46.4	8.4	81.4	46.4	8.4	11491	68.9	1	604	568	1.14
7/11/96	337	Bronxdale	Hotpoint	CTH14CYXLRWH	Automatic	0.0	20	20	2.0	9.0	85.8	57.1	29.7	86.3	46.7	10.2	23272	69.1	1	605	503	1.01
7/18/96	62	Bronxdale	Hotpoint	CTH14CYXLRWH	Automatic	0.0	60	40	2.0	9.0	83.7	47.2	8.8	83.7	47.2	8.8	4065	65.0	0	570	510	1.02
7/18/96	337	Bronxdale	Hotpoint	CTH14CYXLRWH	Automatic	0.0	20	20	2.0	9.0	86.3	46.7	10.3	86.3	46.7	10.3	18941	56.2	1	492	418	0.84
8/ 1/96	3	Bronxdale	Hotpoint	CTH14CYXLRWH	Automatic	0.0	50	0	2.0	9.0	81.1	47.5	7.4	81.1	47.5	7.4	362	111.4	0	976	924	1.85
8/ 1/96	166	Bronxdale	Hotpoint	CTH14CYXLRWH	Automatic	0.0	50	0	2.0	9.0	80.6	53.4	36.2	83.4	49.8	20.6	17256	103.9	1	910	829	1.66
8/ 1/96	30	Bronxdale	Hotpoint	CTH14CYXLRWH		0.0	35	25	2.0	9.0	81.5	47.2	4.9	81.5	47.2	4.9	1514	50.0	0	438	412	0.83
8/ 8/96	306	Adams	Hotpoint	CTH14CYXLLWH	Automatic	0.0	70	40	2.0	9.0	81.8	44.6	7.9	81.8	44.6	7.9	29811	97.4	1	853	798	1.60
8/8/96	196	Bronxdale	GE	CTH14CYXLLWH	Auto	0.0	10	0	2.0	9.0	69.0	41.7	8.5	65.0	39.6	9.6	16440	83.7	1	734	974	1.95
8/8/96	196	Bronxdale	GE	CTH14CYXLLWH	Auto	0.0	30	5	2.0	9.0	77.0	39.6	6.7	74.0	38.4	8.9	8420	42.9	1	376	402	0.80
8/8/96	196	Bronxdale	GE	CTH14CYXLLWH	Auto	0.0	5	3	2.0	9.0	82.0	45.6	7.7	78.0	42.3	7.9	8043	41.0	1	359	349	0.70
8/8/96	195	Bronxdale	GE	CTH14CYXLLWH	Auto	0.0	50	75	2.0	9.0	84.0	47.0	13.7	79.1	59.2	13.9	11660	59.8	1	524	486	0.97
8/8/96	195	Bronxdale	GE	CTH14CYXLLWH	Auto	0.0	50	100	2.0	9.0	85.0	44.5	2.7	82.0	42.4	2.9	13500	69.2	1	606	550	1.10

Audit			Refrigerator Type		Features	Frost	Food Loading		Temp Control		Temperatures (Start)			Temperatures (End)			Raw Usage		I	Annualized Consumption		
Date (-)	Duration (hr)	Site (-)	Manufacturer (-)	Model No. (-)	Defrost (-)	Accum (in)	Refrig. (%)	Freezer (%)	Setting (-)	Scale (-)	Ambient (°F)	Refrig. (°F)	Freezer (°F)	Ambient (°F)	Refrig. (°F)	Freezer (°F)	Energy (Whr)	Watts (W)	(-)	Raw (kWh/yr)	Adjusted (kWh/yr)	Fraction (-)
8/8/96	195	Bronxdale	GE	CTH14CYXLLWH	Auto	0.0	30	20	2.0	9.0	84.0	42.6	10.2	81.0	41.2	8.4	12940	66.3	1	581	537	1.08
8/8/96	195	Bronxdale	GE	CTH14CYXLLWH	Auto	0.0	75	60	2.0	9.0	87.0	39.1	18.0	85.0	44.6	17.2	15890	81.3	1	712	611	1.22
8/8/96	196	Bronxdale	GE	CTH14CYXLLWH	Auto	0.0	60	75	2.0	9.0	85.0	35.1	2.5	81.0	34.2	4.5	11890	60.8	1	532	493	0.99
8/8/96	196	Bronxdale	GE	CTH14CYXLLWH	Auto	0.0	60	100	2.0	9.0	83.5	45.1	12.3	80.2	42.0	11.1	10590	54.1	1	474	442	0.89
8/8/96	196	Bronxdale	GE	CTH14CYXLLWH	Auto	0.0	45	15	2.0	9.0	90.0	32.0	3.5	85.0	35.0	5.5	16760	85.4	1	748	643	1.29
8/8/96	196	Bronxdale	GE	CTH14CYXLLWH	Auto	0.0	20	5	2.0	9.0	83.0	45.1	11.3	79.0	42.0	10.9	10970	55.8	1	489	465	0.93
8/8/96	197	Bronxdale	GE	CTH14CYXLLWH	Auto	0.0	20	5	2.0	9.0	88.0	44.5	12.0	83.0	47.0	12.4	10390	52.8	1	463	399	0.80
8/8/96	197	Bronxdale	GE	CTH14CYXLLWH	Auto	0.0	80	100	2.0	9.0	85.0	46.0	5.2	80.0	48.0	5.9	18160	92.3	1	806	744	1.49
8/8/96	697	Bronxdale	GE	CTH14CYXLLWH	Auto	0.0	60	50	2.0	9.0	82.4	46.3	15.7	79.0	43.2	13.4	39760	57.0	1	499	477	0.96