Evaluating Alternative Simple Rules for Choosing Refrigerators to Replace

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ABSTRACT

Many states are currently introducing electric baseload components into their low-income weatherization programs. Often these baseload efforts involve replacing refrigerators. The challenge for the program designer is to define the effort so that it will fit into the routine of the weatherization teams while keeping the probability of replacing efficient refrigerators low. While many evaluators would like teams to monitor refrigerators for extended periods of time in order to accurately estimate annual electricity usage, program administrators generally reject such extended monitoring. Accurate estimation of energy savings involving before and after monitoring place significant demand on available resources, thus potentially limiting participation in this worthwhile program.

This paper will include a brief review of the measurement versus rules debate. It will discuss the preference for rules by the low-income weatherization program as it grows to include an electric baseload component and will present a new dataset that can offer insights into the usefulness of some simple rules for selecting refrigerators to replace. The paper also will show test results from these simple rules and will discuss possible implications and uses.

Introduction

Refrigerators currently provide a unique energy efficiency opportunity. Frequently one must wait until the end of the service life of almost any other durable good to justify replacement on cost savings. The fact that a lower operating cost can be achieved with a new, energy efficient product generally does not offset the purchase cost. For instance, replacing a furnace might cost $2,600 if one chooses a standard 80 percent model and $3,000 for a more efficient 90 percent unit. The annual heating cost savings with the high efficiency unit for a 2000 square foot home in the Midwest using 10 Btus per square foot per heating degree-day at 60 cents per therm, however, would be around $75 per year. The $75 annual savings will pay for the incremental cost of the energy efficient furnace when the old furnace needs to be replaced, but it will not pay for the $3,000 needed to replace an installed 80 percent furnace that is working well.

Refrigerators today are different. Due to the enormous improvement in the energy efficiency of units on the market in recent years and the relatively stable purchase cost of new refrigerators, the discounted operating cost savings of replacing an old unit that still operates at its factory specifications with a new model meeting the current minimum efficiency standards frequently are large enough to pay the entire purchase price. As an example, the average automatic defrost refrigerator manufactured in 1985 with a top mounted freezer used 1077 kilowatt-hours per year (AHAM). A similarly sized unit (20 cubic feet) using 490 kilowatt-hours per year can be purchased at discount stores in the Midwest for slightly under $400. At 10 cents per kilowatt-hour, the annual operating cost savings of nearly $60 can provide a discounted income stream that pays for the entire $400 purchase price at most reasonable interest rates. In fact, most older refrigerators do not operate at their factory specifications (Kinney and Cavallo: 2000, p. 11 and Moore: 2001, p. 9) and will be much more attractive candidates for replacement. Moreover, it has been found that the length of refrigerator life cycles can be considerably longer than commonly thought (Meier: 2001). Refrigerators can operate much longer than 20 years. These older refrigerators can provide larger annual energy savings than the example above because refrigerators manufactured in the early 1980's and the 1970's generally consumed substantially more energy. Especially in the home of low income families where very old refrigerators are operating well below original performance levels, annual operating cost savings refrigerators can be found to be a good deal greater than $100 per year.

Despite the cost-effectiveness of replacing many refrigerators currently in homes and apartments, the problem of identifying the high energy units – the energy hogs – remains. Consumers can not easily see from their electric bills whether their refrigerators are energy hogs. Even within utility or government programs, like the national weatherization program, energy professionals may not be able to easily identify good candidates for replacement.

The purpose of this paper is to report on an investigation of some simple, observable rules that have been suggested as capable of identifying candidate refrigerators for replacement. These rules are said not to have a high likelihood to choose efficient refrigerators for replacement. Test results for a new dataset will be discussed and presented.

Measurement Versus Rules

The writers of this paper have discussed issues of measuring refrigerator energy use in previous papers. In an article in ***Home Energy***, it was argued that "the only way to acquire reasonably accurate information on individual refrigerators is to monitor them" (Cavallo and Mapp: 2000a, p. 32). The basis of this assertion is a finding that in a dataset of 150 units monitored in situ at three public housing authorities some refrigerator were found to use more than 3.25 times their rated energy usage while on average the units consumed 17 percent more than their rated energy usage. By examining bootstrapped[1] random samples of consecutive 10-minute readings of observations from monitored units, however, it was concluded that "robust estimates of the average electricity consumption for a stock of refrigerators can be obtained by sampling two-day's worth of consumption for each unit" (ibid., p. 35). Others have argued differently and suggested that "a metering time as short as one hour may be adequate to arrive at a fairly accurate estimates of the annualized energy use of a given unit, when metered data are adjusted for kitchen temperature and time of day…" (Proctor: 2000, p 34).

Separate from arguments about the length of monitoring required to develop accurate estimates of annual energy use, some writers have discussed monitoring for the purpose of identifying refrigerators that may be targeted for replacement. In previous papers (Cavallo and Mapp: 2000a. and Cavallo and Mapp: 2000b.), a method was proposed and discussed which could reliably identify refrigerators consuming inordinately large amounts of electricity. The method required at least 2 hours of monitoring and was not suggested as a means for developing an annual energy consumption estimate. No consensus on this method

[1] Bootstrapping is a Monte Carlo sampling of an empirical distribution that attempts to simulate the underlying population's distribution.

has developed, however. In Kinney (2000), for instance, it was stated that "even for simple replace/don't replace decisions, I believe that testing of automatic-defrost refrigerators should be conducted for well over two hours" (p. 36).

As arguments proceeded over how long one should monitor, utility and local weatherization program administrators have looked for alternatives to monitoring. In particular, administrators have rejected extended monitoring because it will not fit into the routines of the staff that already have many tasks to perform during site visits. Rather than measure the energy consumption of refrigerators, some have looked to rules by which they can identify good candidates for replacement. For instance, Dennis Flack of CSG has said "we use a combination of observation, wisdom from the past, and some easy-to-use software we developed using data from the Association of Home Appliance Manufacturers and field measurements" (Kinney and Cavallo: 2000, p. 10). Also the Wisconsin refrigerator program uses a rule of replacing units manufactured before 1990 (Kinney and Belshe: 2001, p. 12). For consumers that are not eligible for programs, a rule-based method has been offered by ***Home Energy*** based on the DOE energy ratings (Cavallo: 2001) and is available on ***Home Energy***'s web site (http://www.HomeEnergy.org/consumerinfo/refrigeration2/). The rule-based methods for selecting refrigerators to be replace have become more important with the recent change in the national weatherization program to include electric baseload measures. By updating its regulations regarding electric baseload measures, this DOE program has dramatically enhanced the potential of lowering the electric bills of its low-income clients and reducing the environmental damage associated with wasted electricity used by inefficient refrigerators.

The national leadership of the weatherization program has wisely decided to strike a balance between basing the replacement of refrigerators entirely on rules and requiring all units to be monitored. The DOE requirements for refrigerator replacement state that monitoring must be done for at least 10 percent of the units replaced (Moore: 2001, p. 3). This requirement, if appropriately integrated into a dynamic rule-based selection system, can provide an effective means for identifying rules that will be relevant to the needs of programs and will change as more information about the stock of refrigerators is acquired.

Developing Data for Tests

As noted above, Wisconsin has chosen to organize its refrigerator replacement program around the rule that all units manufactured before 1990 are eligible for replacement.[2] As with most good rules, the Wisconsin rule is easy to communicate to program staff, requires no calculations in the field, can be implemented without adding more than a few minutes to the time that staff spends with clients, and can be expected with a very high likelihood to replace units that have a savings to investment ratio greater than 1. Despite the confidence that the Wisconsin Division of Energy had in the use of this rule, it decided to support an analysis of this and several other simple rules that could be implemented. The Division of Energy funded a project to collect data on refrigerator energy consumption through monitoring. It also collected information that could be easily observed by utility or weatherization program staff in the field.

[2] Wisconsin restricts participation in the replacement program to refrigerators that are 10 cubic feet or greater.

The data collected so far in the project included one week's worth of monitored energy usage, model and serial numbers, color of the unit, location of the nameplate, temperature differential across the food compartment wall, general condition of the unit, and the settings of the unit (energy saver switch, temperature setting, etc.). The data was collected in the kitchens of weatherization clients with the assistance of Craig Baumstark and Tim Huck of the Racine/Kenosha Community Action Agency and at a refrigerator recycling center operated by CSG Services, Inc. with the aid of Barbara Doubek. In addition to collecting data to use in testing the efficacy of simple rules, the monitoring of refrigerators at a recycling center provided an opportunity to examine whether the information acquired at the center is statistically similar or different from that acquired in client kitchens. The value of discovering such similarity or difference could be great since monitoring in a recycling center provides weatherization agencies with a means of fulfilling the requirement of monitoring at least 10 percent of the refrigerators replaced without taking staff time away from other duties during a site visit. Monitoring at a recycling center also enables the monitoring of refrigerators for more extended periods of time, such as periods greater than 2 days, which would eliminate the problem of shorter measurements that might or might not include a defrost cycle. It additionally could increase the value added by responsible recycling facilities.

Table 1. Test of Difference of Means for Two Samples

	Cudahy	Racine/Kenosha	Difference
Average kWh	1209	1257	48
Standard Deviation	427.46	386.42	
No. of Observations	19	12	
Critical Value*			310.50

* The critical value is the maximum difference between the two means at which they can be said to be not significantly different.

The data used in this paper show results from the monitoring of 31 refrigerators. Nineteen were monitored at the recycling center. Twelve were monitored in the kitchens of the Racine/Kenosha weatherization clients. Table 1 compares the measurements made at the two locations. The average energy consumption of the units monitored in the recycling center was 1209 with a standard deviation of 427.46. The average for the units monitored in the Racine/Kenosha kitchens was 1257 with a standard deviation of 386.42. The difference between the two means is 48. A statistical test of these two means to see if they are significantly different at the 95 percent level of significance proved negative (i.e., they are not statistically different) because one could expect a difference in the means as great as 310.50 (the critical value in Table 1) with the two means coming from the same underlying distribution. To test if the two samples were actually different groups of models, the energy ratings of the two samples were examined. Table 2 presents the results. The average energy rating of the units tested at the recycling center was 1169 with a standard deviation of 332.59., while the units from the Racine/Kenosha kitchens had an average of 1009 with a standard deviation of 213.1. A test of these two means showed that they are not statistically different at a 95 percent confidence level. As a result of these tests, it was concluded that at least for this recycling center and this weatherization agency there is no significant difference in sampling results and that the two samples can be considered to be from a single population.

Table 2. Test of Difference of Means for Two Samples

	Cudahy	Racine/Kenosha	Difference
Average Rating	1169	1009	160
Standard Deviation	332.59	213.14	
No. of Observations	19	12	
Critical Value			220.67

Simple Rules

Many rules can be defined to screen refrigerators for replacement, and the success of implementing the rules will likely vary across programs and teams. It would seem reasonable to assume that rules will be beneficial if they are easy and inexpensive to use, if they provide a high probability of selecting high use refrigerators, and if they have a low probability of mistakenly selecting units that are not energy hogs. Four simples rules are considered and tested here. They are as follows:

Rule 1: Replace units with energy ratings above an annual kilowatt-hour which will give a savings to investment ratio of one or greater.
Rule 2: Replace units manufactured before a particular year.
Rule 3: Replace units of a color popular during a particular historical period but no longer used.
Rule 4: Replace units with the nameplate attached in a location that is no longer used.

These rules have been suggested for use by programs at different times, but the current writers have not seen empirical tests of their validity.

The particular specification of Rule 1 was defined so as to choose refrigerators with energy ratings above 849 kilowatt-hours. The value 849 was chosen using the ***Home Energy*** web calculator. It assumes a replacement refrigerator cost of $400 and a local electric rate of 8 cents per kilowatt hour. Rule 2 was specified as it is for the Wisconsin program – replace units manufactured before 1990. The colors used for selection within Rule 3 were Brown, Gold, and Green. The final rule, Rule 4, was based on the assertion that older refrigerators had nameplates near the base of front frame of refrigerators, whereas current models have the nameplates inside the food compartments.

Each of these rules are specified so as to define a discrete decision criterion. For instance, the nameplate of a refrigerator is either at the base of the front frame or it is not, and the color of the refrigerator is either one of the three stated above or it is not. The dichotomous nature of these rules make them simple to implement. That same nature makes them easy to test. For the tests below, it is assumed that one should replace all units with estimated energy consumption levels of 850 kilowatt-hours per year or more. A rule should be considered somewhat unsatisfactory if it selects units for replacement which have monitored usage of less than 850 kWh/yr or if it does not choose for replacement units which have monitored usage at or above that level. As will be seen, some rules may be effective if used in conjunction with an additional selection method.

Tests

Of the 31 units in the samples, Rule 1 would have selected 26 for replacement and left 5 units in the kitchens of the clients. The average monitored energy usage of the units that would have been selected was 1326 with a standard deviation of 365.67. The average usage of those which would not have been selected was 719 with a standard deviation of 124.98. A test of the difference between these two averages, shown in Table 3, was significant, indicating that the rule discriminates between two distinct underlying populations. This rule would have incorrectly chosen two units for replacement which had monitored energy consumption levels under 850 and would have not selected one unit that had a monitored rate above the cutoff level.

Table 3. Test of Rule based on Energy Rating (Rule 1)

	Energy Rating at or above 850 kWh	Energy Rating below 850 kWh	Difference
Average kWh	1326	719	607
Standard Deviation	365.67	124.98	
No. of Observations	26	5	
Critical Value			341.70

Rule 2 would have selected 23 units for replacement and not included 8 refrigerators in the replacement program. The refrigerators that would have been included in the program had an average monitored consumption of 1258 kWh/yr with a standard deviation of 376.16. The average for the units that would not have been selected for replacement was 1064 with a standard deviation of 487.07. Table 4 presents the results for this rule based on the age of the refrigerator. The difference between these two averages is not significant at the 95 percent confidence level. This is due to the large standard deviations for each. It is interesting to note that 3 of the 23 units that would have been selected for replacement had energy consumption levels below 850 kWh per year and five of the 8 units that would not have been chosen for replacement had energy consumption levels at or above 850.

Table 4. Test of Rule based on Year of Manufacture (Rule 2)

	pre-1990	1990 or Later	Difference
Average kWh	1258	1064	193
Standard Deviation	376.16	487.07	
No. of Observations	23	8	
Critical Value			340.06

Rule 3 would have replaced 7 units and would have left 24 refrigerators in place. The average measured consumption for the refrigerators with now-undesired colors was 1433 kWh/yr with a standard deviation of 416.36. The average for the other units was 1168 kWh/yr with a standard deviation of 391.59. As shown in Table 5, these averages are not significantly different based on a test of the differences of two means. Rule 3 was successful in selecting only refrigerators with energy consumption levels measured to be at or above 850 kWh/yr. However, this rule would have left 17 units in place that had measured consumption levels above the cutoff.

Table 5. Test of Rule based on Color of Unit (Rule 3)

	Green, Brown, or Gold	Other Colors	Difference
Average kWh	1433	1168	265
Standard Deviation	416.36	391.59	
No. of Observations	7	24	
Critical Value			348.10

Only the units monitored at the Cudahy recycling center collected information on the location of the nameplate. As a result, fewer units (19 as opposed to 31) can be examined for the appropriateness of Rule 4. Of the 19, 12 refrigerators had nameplates at the base of the front frame of the unit. Seven refrigerators had nameplates inside the food compartments. The average energy consumption of the units with nameplates on the front frames was 1459 with a standard deviation of 305.00. The average for the units with nameplates in the food compartments was 780 with a standard deviation of 193.47. Table 4 displays the test of the difference between these two means. It is shown that the difference was statistically significant at a 95 percent level of confidence. Rule 4 was successful in selecting for replacement only units that had monitored usage levels at or above 850 kWh/yr. The rule incorrectly excluded from replacement 3 units that had monitored usage at or above that cutoff level.

Table 6. Test of Rule based on Location of Nameplate (Rule 4)

	Nameplate on Lower Frame	Nameplate in Food Storage Compartment	Difference
Average kWh	1459	780	679
Standard Deviation	305.00	193.47	
No. of Observations	12	7	
Critical Value			271.88

Additional Rules

The four rules presented above do not nearly exhaust the rules that could be used in refrigerator replacement programs. One additional rule that was not tested with this data relates to the use of fiberglass insulation. Early refrigerator models used fiberglass insulation. This insulation was subject to failure. Water would leak on to the freezer compartment or condense on it and freeze. This produces a thermal bridge that degrades the insulating value of the fiberglass. These units when removed and stored can drip water for days as the ice melts and drains onto the floor. It is said that feeling the top exterior surface can identify a fiberglass-insulated unit. The lack of insulation around wiring and tubing that pass into the freezer compartment result in a cold spot on the top which can be identified. Fiberglass also has little lateral structural strength. It is said that another simple test for fiberglass insulation is to open the door of the unit and using both hands press together from the outside and inside at the same time. If there is fiberglass insulation, the wall will flex. The introduction of rigid foam insulation increased the rigidity of the refrigerator compartment walls. The same test would indicate a stiff wall with little "give". Foam insulation, it is said, first began to appear in the mid 1980s, about the same time that the nameplate first moved from the lower edge into the interior of the food compartment. Only after about 1992 did rigid foam insulation become fully integrated into the door construction. Previous to that fiberglass was still the insulation of choice. Fully integrating rigid foam insulation into refrigerator construction resulted in a more efficient unit. Therefore a possible well specified rule could be:

Rule 5: Remove all units with flexible walls containing fiberglass insulation.

In addition, one finds that over time various manufacturers have entered or left the market. Refrigerators have been marketed under various brands. A frequently found example is the Sears Kenmore models marketed under the Coldspot label. This label appeared on the door until about 1978. Any refrigerator with a Coldspot brand or label is, therefore, more than 20 years old. Coldspots may be a good candidates for removal and recycling. In order to investigate the value of this selection criteria, a table of all brands listed in AHAM catalogs can be developed. For each of the semi-annual guides, the appearance of models indicated that one would find examples of that brand for that year. Models that have not appeared since the mid 1980s include: Coldspot, Coronado, J C Penny, O'Keefe & Merritt, and Wizard. Signature ceased production in 1982 but reappeared in the early 1990s. Removal of all Signature except for obviously newer models could also be used to select older, less efficient models. Thus a rule could be designed as:

> **Rule 6:** Remove all models of brands that ceased production by the mid 1980s. These include: Coldspot, Coronado, J C Penny, O'Keefe & Merritt, and Wizard.

The two additional rules defined here create easy to implement dichotomous choices. Though they have not been tested with the dataset developed so far within the Wisconsin project, these rules could be tested with the statistic methods given above. The updated regulations for monitoring 10 percent of the refrigerators within the weatherization electric baseload program could provide a good source of information for testing and refining such simple useful rules.

Becoming a Bayesian

If measuring the energy consumption of every refrigerator were a costless process, there would be no need for rules – simple or elaborate – to choose which units to remove from homes and which to leave in place for the resident to replace at some distant future date. However, with program administrators rejecting extended monitoring due to the cost in staff time, programs will use selection rules. These rules will either be used instead of monitoring or used in conjunction with some monitoring.

It would seem to be a wise course of action to incorporate some monitoring in programs. By monitoring, program administrators can identify and adopt good rules. Good rules should have the characteristics of being easy to communicate to program staff, requiring no calculations in the field, using up little staff time to implement, and having a high likelihood of choosing the right units to replace. Monitoring is particularly important in assuring that the rules used will have a high likelihood of choosing inefficient refrigerators for replacement. For this reason, it would seem very important to collect accurate information from monitoring. To collect such accurate information, monitoring for extended periods of time is essential.

In addition to identifying and adopting good selection rules, monitoring enables administrators to adapt rules to changing circumstances. The methods used in this paper provide a way to test and adapt rules for a refrigerator replacement program. In a sense, it offers a way for program administrators to become Bayesian. One does not need to know all that there is to know about refrigerators immediately. Instead one can create a rule that seems reasonable, try it, collect data, and test for efficacy. It also allows for rules to change as programs or the stock of refrigerators change.

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