Targeting Refrigerators for Repair or Replacement

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Abstract: Refrigerator energy use is a dominant component of total energy use for many low-income households. Poorly operating or inefficient refrigerators can place an unnecessary financial burden on those households or the public agencies that pay their electricity bills, such as housing authorities. This paper presents an analytic tool that is low cost and easy to use. The procedure can be implemented with minimal staff training. The tool enables housing providers or weatherization agencies to identify poorly operating or high use refrigerators and target them for replacement or repair. The use of the procedure is illustrated, and its value for participants in a bulk refrigerator purchase and replacement program is discussed.

Introduction

Refrigerators use more energy than any other kitchen appliance. In many low-income households that do not have air conditioning, the refrigerator uses as much - and sometimes more - electric energy than all other uses put together. As a high energy user, the refrigerator should be the target for energy programs to save energy dollars for the household or the public agency paying the energy bills.

For several years, the authors have been collecting detailed information in field studies of refrigerators at housing authorities in Chicago, Pittsburgh, and Milwaukee. These studies have been used to develop baseline and performance data for energy performance contracts that have purchased and installed energy efficient replacement refrigerators under a bulk appliance purchase program sponsored by the U.S. Department of Energy and the Consortium for Energy Efficiency (CEE). Wide variation was found in the energy usage of refrigerators, with approximately one-half of older refrigerators using more than 1.2 times the rated usage of the models and some individual units consuming more than 2.5 times the rated usage. One may expect similar findings in non-public housing in low-income communities, and one may also expect to observe this result in households in which refrigerators are purchased from second-hand dealers.

The opportunities for energy and operating cost savings can be substantial. For instance, we found that the average annual electricity usage of refrigerators in the Chicago Housing Authority's apartments was 976 kWh. At a base rate of 9 cents per kWh[1], the cost of operating the average unit would be about $88 per year. For units operating among the highest 10 percent of energy usage - greater than 1.6 times the rated usage - the annual operating costs of the refrigerators at 9 cents per kWh is over $117. The energy efficient replacement refrigerators were found to consume approximately 480 kWh in the CHA apartments. As a result, the expected operating costs of the new units is about $43.

The bulk purchase program for refrigerators that CEE has been administering enabled the CHA to purchase new energy efficient Magic Chef units (model no. CTN1511AEW) at approximately $320. At this price, the payback period for replacing an average unit with an energy efficient model at 9 cents per kWh is about seven years. The payback period for replacing the 10 percent highest energy users would be less than four and a third years.

[1] Currently 9 cents per kWh is the approximate initial block rate in the Chicago area with taxes and other charges included.

In an earlier paper, the authors presented a simple method for developing an accurate baseline of the energy usage for a stock of refrigerators (1). Here the focus will be on the identification of poor performing refrigerators - such as those using more than 1.6 times their rated usage. The reader will see that using the method described housing authority or weatherization staff can capture the savings associated with the replacement or repair of the highest energy using refrigerators.

Some Signature Refrigerator Characteristics

One can begin by recognizing two very common characteristics of most refrigerators. Over a broad range of models and vintages, the operating characteristics of refrigerators appear the same. A refrigerator turns on, runs for a while, turns off and is off for a while. It then turns on again and the cycle repeats. A typical, steady-state cycle is about 40 minutes with the duty cycle, or per cent running time, being about 50 percent for standard temperature differences between the food compartment of the refrigerator and the room in which the refrigerator is placed.[2] In other words, a typical, properly operating refrigerator runs about 20 minutes and is off 20 minutes.[3] For automatic defrost models, a second cycle is superimposed on top of the primary cycle. The defrost cycle commonly runs with an 18 to 36 hour period and displays a sharp peak for only 10 to 20 minutes.

The characteristics of the primary cycle has been remarkably stable at 40 minutes for thirty or more years. As refrigerators grew larger, the compressors have gotten larger. The running times have not observedly changed to compensate for the additional heat that has needed to be dissipated. Similarly as the insulation levels and their effectiveness have increased over recent years, there has been no change in the duty cycle. Temperature controllers limited the internal temperature swing so that the off time has remained about the same.

A typical refrigerator monitored for a five-day period is shown in Figure 1. The abscissa shows the number of 10 minute periods in which the average wattage was logged. The ordinate shows the average watts used in that 10 minute period. One sees the pronounced, regular spikes of the defrost cycle occurring here on an approximate 24 hour period. One also notices the frequent, smaller peaks followed by off periods. This primary cycle takes about 40 minutes. The data for Figure 1 was collected using a Brultech KWH Datalogger. This device enabled the authors to collected similar profiles of the usage patterns for nearly 100 refrigerators of various makes, models, and vintages. Additional refrigerators were monitored using line loggers that showed accumulated energy consumed but did not allow the usage profile to be examined and captured. The line loggers used in the data collection were from Pacific Scientific Instruments. The loggers can display the voltage and current on the line as well as the accumulated Watt-hours since it was last reset.

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[2] The temperature difference between the food compartment and the kitchen around the refrigerator obviously is important. A good food compartment temperature is 38°F, and a reasonable kitchen temperature is 73°F. The temperature differential across the refrigerator's wall is thus 35°F. Increasing the temperature differential by lowering the food compartment temperature or raising the kitchen temperature will increase the run time of the unit. The author's report in (1) that each 1°F increases energy use by approximately 2.25 percent. Other researchers (2) found a similar result.

[3] The cycle is, of course, altered temporarily when one puts a large warm roast in the refrigerator after a Sunday afternoon meal. But the steady state cycle will return after the roast is cooled to the set temperature.

Analyzing the profile results taken with the Brultech loggers, however, enabled the researchers to better interpret the data returned from the line loggers.

Developing an Analytic Method

The relative constancy of the primary cycle can be used to develop criteria for the selection of refrigerators that are operating outside acceptable ranges and using inordinately large amounts of electricity. Moreover this selection can be accomplished using the less expensive and easier-to-use line loggers rather than the 10 interval profile loggers.

The basic method for identifying poor performing units can be implemented in a 2 hour period, which is about the time required for a typical HERS site visit in Wisconsin or a standard weatherization audit. The auditor needs to measure only the Watt-hours of energy used by the refrigerator during the 2 hour period, apply some common sense (to be discussed below), and compare the results to Figure 2, the Refrigerator Assessment Tool.

Figure 2 is based on the observation that a properly operating refrigerator will repeatedly consume electricity for about 20 minute and then use little or no power for an equal amount of time. A refrigerator that uses 200 Watts during its duty cycle should be expected to use accumulate about 200 Watt-hours over a two hour period. That would indicate that during the 3 forty minute periods the refrigerator had spent half of each period drawing 200 Watts and half using little or no power. Units that are operating poorly will often be running 100 percent of the time or nearly so. If the auditor measures a unit that uses 200 Watts during its duty cycle and finds that over a two hour period it has accumulated 400 Watt-hours, then he knows that the unit has not been cycling as it should.

Figure 2 shows Watts along the abscissa and kWh along the ordinate of the graph. The ordinate is given for a one-hour period, so if one monitors the unit for two hours he should divide by 2. The highest sloped line displays the average hourly kWh that would result from a refrigerator drawing a particular demand in Watts during the duty cycle if the unit ran 100 percent of the time. The next lower sloped line displays the average hourly kWh that would result from a unit that ran 70 percent of the time. Similar sloped lines give the relationship between the kWh and Watts for 60, 50, 40, and 30 percent runtimes.

The figure has three basic regions. If one records an observation in the region above the 100 percent line, one should look at his numbers again. There must be some error since one can not get an average hourly kWh that is greater than the peak demand. This data error region in the upper left-hand portion of the graph is shaded most heavily.

The white, or unshaded, area is the region which indicates a likelihood of acceptable performance. Refrigerators falling into this region will likely be using less than .15 kWh on a regular basis. A unit using as much as .15 kWh each hour of the year would consuming around 1300 kWh on an annual basis, which is the borderline for the highest 10 percent of energy usage in the refrigerators monitored by the authors at public housing authorities. The region is truncated at 250 Watts so that units with larger demand requirements are removed from households and replaced with more efficient, lower demand models.

The largest region of the figure is the lightly shaded area. This region indicates that the units are excellent candidates for replacement or repair. Most important here is the area near the 100 percent diagonal line. Units that have duty cycles throughout or nearly throughout the measurement period are likely to be very high operating cost refrigerators. Again it is noted that the region includes all units drawing more than 250 Watts so that units they can be removed from the households and replaced with more efficient, lower demand models.

The selection criterion for replacement or repair that is included in the figure, then, displays three characteristics:

- the demand during the duty cycle is greater than 250 Watts
- the average hourly kWh over the measurement period is greater than .15 kWh
- refrigerator runs more than 70 percent of the time during the measurement period

These characteristics defines the shaded region.

One may consider these characteristics too lenient, and that such a selection criterion would allow too many poorly performing units to remain in households. Though the authors are not sympathetic to this view, two things should be considered. First, the method is intended to ferret out the most costly units to operate. This method has a very good likelihood of identifying refrigerators are consuming in the highest 10 percent of the stock of a housing authorities.

A second consideration that should be kept in mind is that a high reading could result from the defrost cycle occurring during the measurement period. One can see from Figure 1 that the peak of the defrost cycle is twice the duty cycle demand. Though the defrost cycle peak last only 10 to 20 minutes, it can cause a substantial error in estimating the average energy use. This potential estimation error is reduced by averaging the energy usage over a two hour measurement period. The likelihood of discarding an otherwise good refrigerator is also reduced by building in a marginal of safety in the selection criterion.

Some Common Sense Considerations

As noted earlier, the auditor needs to apply some common sense when investigating the energy used by a refrigerator. First and foremost, it needs to be remembered that the purpose of a refrigerator is to keep food at safe temperatures. It is usually recommended that food should be kept at below 40ºF and above freezing in the food compartment, with 38ºF being a safe and economical temperature for most refrigerators. If the auditor finds that all of the food in the unit is noticeably above 40ºF, he should ask the resident if this is a common and continuing occurrence. Replacement or repair of the refrigerator will be necessary regardless of the energy consumption if it is not keeping food at safe temperatures.

Second, the auditor should take note of any large, warm food items or pots that appear to have been recently placed in the refrigerator. If the auditor measures a unit that is cooling a massive roast or turkey, he is likely to find the refrigerator compressor running throughout the measurement period. Again the auditor should make use of any knowledge the resident may have regarding the how recently the food was put into the unit and avoid gathering false data.

Third, the auditor should inspect the refrigerator for obvious repair needs. If the unit has damaged gaskets or a twisted and poorly fitting door, the unit may indicated the need for repair or replacement without taking an energy measurement. Or if the electrical outlet or cord is very hot, it may suggest an electrical short. Also if water is dripping from the freezer compartment into the food storage area or onto the floor, the defrost cycle may be malfunctioning. These and other common sense observations should be used by the auditor to keep from blindly making a measurement that will not either provide meaningful results or waste time.

Summing Up

The findings reported above suggest several things. First - and most importantly - the savings from replacing older refrigerators can be substantial. The bulk purchase program from CEE for refrigerators is virtually a no-brainer. Replacing high operating cost refrigerators with energy efficient units that cost the same or less than standard efficiency models will save dollars. Second, one can identify and target the especially high energy use refrigerators without major cost if one follows the monitoring procedure offered above and compares the measurement to the graph in Figure 2. The procedure uses low cost line loggers that are easy to attach and easy to read. Finally, this procedure can be implemented by maintenance staff or weatherization auditors without extensive training. There is thus no need to depend on information collected by energy service company staff or other outside contractors.

One may conclude with a paraphrase of the founder of Faber College from the movie “Animal House”, measurement is good, and add that good measurement need not be costly.

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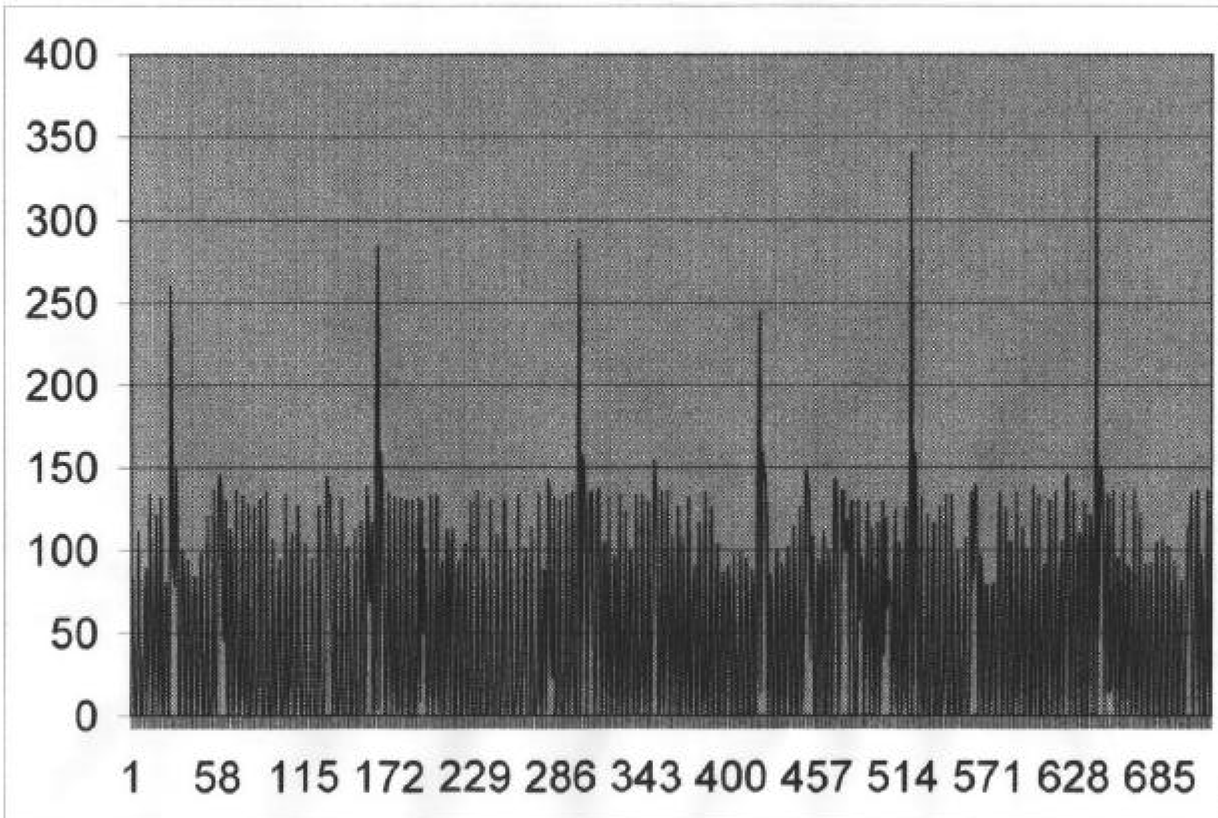
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350
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200
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100
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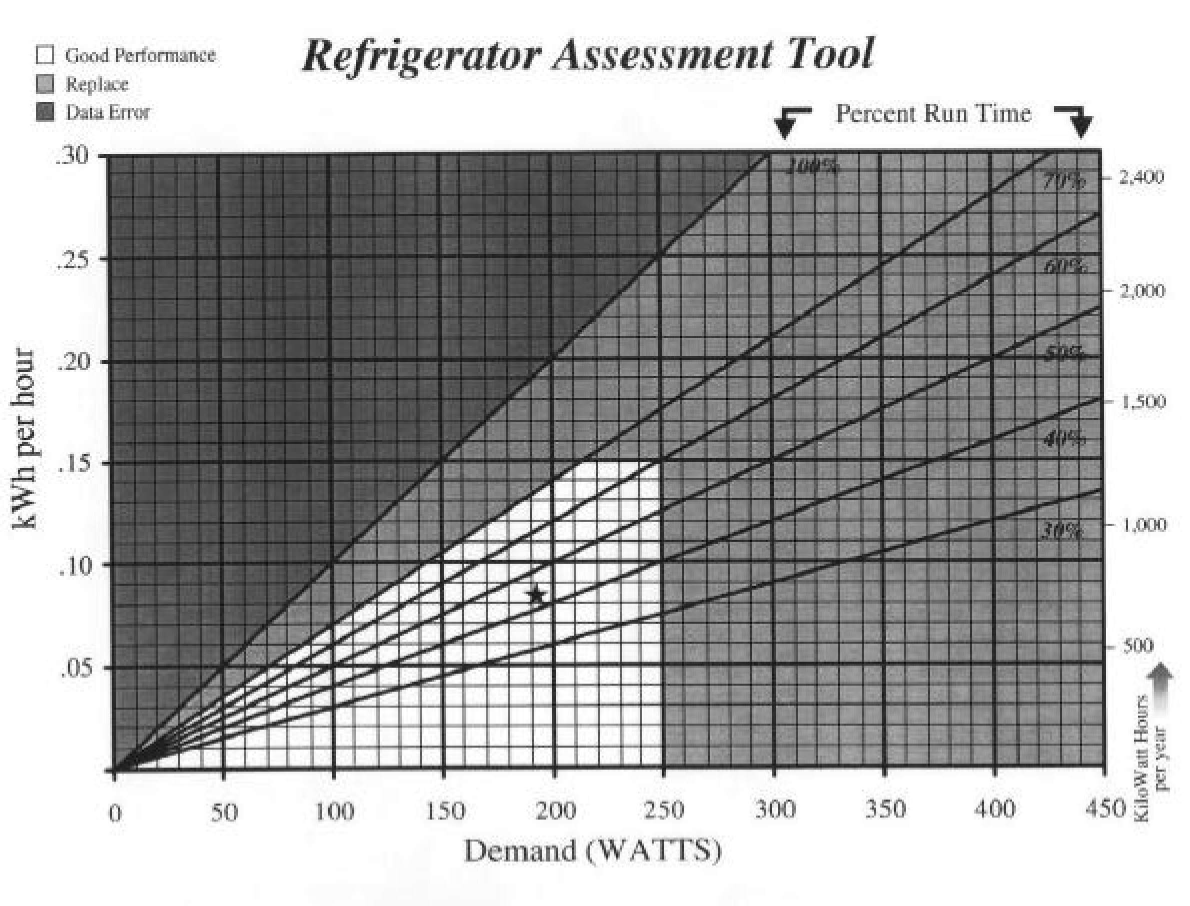
Figure 1



Refrigerator Assessment Tool
Good Performance
Replace
Data Error
Percent Run Time
100%
70%
60%
50%
40%
30%
kWh per hour
.30
.25
.20
.15
.10
.05
2,400
2,000
1,500
1,000
500
KiloWatt Hours per year
0
50
100
150
200
250
300
350
400
450
Demand (WATTS)

Figure 2