# Low-Income Refrigerator Replacement
# Selecting the Worst of the Worst

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## ABSTRACT

The Simplified Refrigerator Selection Criteria was designed to target high usage refrigerators based on high load, high annual usage and evidence that the refrigerator runs most of the time. The selection criteria targets models for replacement that measure more than 250 watts when running, usage of more than 0.150 kWh per hour (1,310 kWh annually) measured over an approximate two hour period and a per cent running time of greater than 70 %. This paper presents the results of a study of nearly 500 refrigerators examined as candidates for replacement. Initial estimates were that approximately 25 per cent of candidates would qualify for replacement. However, actual field measurement qualified nearly 35 per cent of examined models. This placed a strain on available resources. This paper will review the selection criteria; present results of field measurements and discusses what can be learned from the available data. The paper will also present suggestions for improved field measurement techniques and modifications of the selection criteria. This paper documents the energy savings achieved by refrigerator replacement and a preliminary analysis of factors influencing the number of refrigerators replaced.

## Introduction

This paper summarizes the results of the usefulness of simple selection criteria for targeting high use refrigerators under a low-income household assistance program. The selection criteria used a watt meter to determine refrigerator wattage when running, approximate annual energy use and per cent of running time or an equivalent capacity factor. A sample of nearly 500 refrigerators was measured with nearly 40 percent identified as candidates for replacement. The results of the program give a rough estimate of energy savings and reduction in utility system peak demand load. One should, however, be cautious of annual energy reduction estimates from sampling of just 2 hours or estimates that do not measure the temperature delta across the refrigerator wall. Also one should be cautious when using estimates of annual energy savings from just one season of the year. This procedure, nevertheless, is a good method for identifying refrigerators that exhibit very high energy usage as to warrant immediate replacements.

### The Operation of a Refrigerator

In its simplest form, a refrigerator has a compressor to provide cooling through the pumping of chilled Freon through cooling coils in the freezer compartment. The fresh food compartment is cooled through chilled air circulated by a small fan from the freezer compartment. Older refrigerators before standards improved their energy efficiency used fiberglass insulation and often had an anti-sweat heater around the lip of the refrigerator body where the door meets the body. The heater was to prevent moisture from condensing on the gasket used for sealing while the door was closed. New models produced after about 1990 have a high-density rigid foam insulation although some models produced during the 1980s had already moved from fiberglass to foam insulation. For newer models heat conductance through the walls and door is less so the refrigerator needs a smaller compressor to maintain adequate temperature. Older model refrigerators had a larger compressor to compensate for the additional heat that could penetrate the fiber glass insulation. Older models also tend to run for longer periods of time to compensate of the additional heat conductance through the walls. The older models are also more likely to run for long periods when the weather is exceptional hot and humid. New models tend to run for shorter periods of time and be less sensitive to hot weather because less heat penetrates into the refrigerator body.

Selecting older inefficient refrigerators for replacement can be based to several criteria:

- High wattage compressors represent older models with high energy usage.
- High average hourly energy usage represents high energy bills and older inefficient insulation or leaky doors and seals.
- High average per cent run time represents a unit that is in poor repair and has difficulty providing sufficient cooling to maintain adequate temperature control for refrigerated food.
- General condition of the unit or other possible visual inspection for indicators of older or high energy use models.

**The Refrigerator Replacement Program**

The Cinergy Low-Income Refrigerator Replacement Program was designed to reduce the utility expenses of Cincinnati's low-income sector. Cinergy has participated in low-income weatherization program for many years. This program is a piggyback to existing utility weatherization programs in Ohio. Cinergy serves 335,546 residential gas customers and 600,633 residential electric customers in Ohio. Beginning in mid 1999, this program was expanded to include electric measures to enable low-income residents to reduce their electric utility expenses. Refrigerator replacement and air conditioner upgrades were added to the list of allowable measures. The weatherization program is implemented through a contract with People Working Cooperatively (PWC), a local weatherization and service provider. PWC provides home audits to identify weatherization measures and target candidate refrigerators for replacement.

The Cinergy Refrigerator Replacement Program involved an audit of a prospective low-income household participant. Included in the audit was a review of the current refrigerator's operation. Included in the refrigerator component of the audits was an inspection and cleaning of the refrigerator's heat exchanger coils, and a check of the door gasket seal along with a determination to see if the refrigerator closes tightly. Next the refrigerator was plugged into the energy consumption monitor (ECM) and a reading taken to check if the anti-sweat device was operational and if the light went out when the door closed. The Brand, Size, Serial Number and Model Number were recorded as well as the wattage when running after one minute of operation.

The first selection criterion for replacement was if the compressor wattage was greater than 250 watts.

Next the time was recorded and the ECM zeroed. After approximately two hours the time and kWh reading was recorded. The auditor then determined the run time in fractional hours and then divided that into the kWh consumption to obtain an hourly consumption in kWh/hr.

The second selection criteria was to replace a unit that consumers more the 0.150 kWh over an average one hour period. This corresponds to 1,314 kWh annually assuming this was a representative hour.

Next the auditor divided the average kWh consumption over a one-hour period by the wattage in kilowatts. When the refrigerator was running with the door closed. This represents the fractional running time or capacity factor. The final selection criterion was to replace any unit with an average running time of greater than 70%.

If any of these three selection criteria was satisfied, the auditor was to seek authorization form the householder to replace the unit and obtain a signed release.

Previous national models for refrigerator replacement programs (Pratt & Miller 1998) have required extensive metering to select high usage models as candidates for replacement (Kinney & Cavallo 2000) or very simple selection based on visual inspection of the physical condition of candidate replacement models. Both approaches have significant limitations. Extensive metering is time consuming, expensive and may require return visits for monitoring periods greater than one day. The advantage is that accurate estimates of potential energy savings can be obtained. Visual inspection has the advantage that it requires only a short time. However, the selection criteria are difficult to replicate from one auditor to another. In addition, potential energy savings are difficult to obtain unless there is extensive post replacement measurement of refrigerators removed during the program. These measurements occur under a test condition and may not represent actual savings realized under occupant operating conditions.

In order to obtain a balance between accuracy and available audit time, a simplified selection criterion was used to target high usage refrigerators for replacement. The selection criteria was based on a measurement of the wattage drawn while the refrigerator was running, usage during a two hour period and evidence that the refrigerator ran more than 70 percent of the time during the two hour measurement period. These selection criteria were based on sample data from a study of low-income household refrigerators from the Chicago Housing Authority (Cavallo & Mapp 1999). A later study of single family owner occupied residential housing in Wisconsin (Cavallo & Mapp 2000) indicated general agreement when considering that there was no income selection on these householders. The general belief is that low-income households have a population of older, less efficient refrigerators in generally poorer running condition.

The PWC auditors were provided with a wattmeter that recorded both wattage and elapsed kilowatt-hours. The PWC audit requires about two hours. Upon arriving at a residence, the auditor installed the wattmeter and performed an initial assessment of the refrigerator. This included cleaning the coils, a determination of the general condition of the refrigerator and recording the wattage while the refrigerator was running. At the end of the audit, the elapsed kWh was recorded as well as the elapsed time. The kWh consumption per hour during the measurement time was determined as well as the ratio of the kWh per hour divided by the operating wattage in kilowatts. The ratio indicates the fraction of time the refrigerator was operating during the approximate two-hour audit.

When a refrigerator is identified as a candidate for replacement, the owner is asked if they wish to receive a replacement model. The replacement models are Energy Star qualifying Top Freezer models with Automatic Defrost. The resident is eligible to receive either an 18 or 21 cubic foot model. The estimated annual energy use based on the federal test procedure for these ENERGY STAR models is less than 558 kWh for the 18 cubic foot model and less than 604 kWh for the 21 cubic foot model. The assumed annual energy usage for the average replacement model used in this program is the average or 580 kWh per year. The approximate cost is $500 for the first or $700 for the larger size. The actual replacement is contracted to Custom Distributors of Cincinnati. They deliver and install the new ENERGY STAR model. They also remove the current refrigerator and recycle the components so that this high use refrigerator is removed from the load. After installation of the new ENERGY STAR model, PWC will return to the site to check the installation and provide follow up and general energy training.

The original program design anticipated an annual replacement rate of between 20% and 25%. The actual replacement rate has been closer to 35%. The program expended resources at a faster rate than expected however an initial estimate of the savings indicates average savings of 1,900 kWh/yr. for the replacement refrigerators. This paper represents a reexamination of the initial assumptions and the actual savings.

Refrigerators are often targeted for replacement because they represent one of the largest users of electrical energy in a typical low-income household. Only an electric water heater or electric space heating is likely to be a larger electrical load. Refrigerators also have the added advantage that they are relatively easy to monitor, easy to remove and replace and their operation is less subject to occupants control. For example the thermostat setting on a furnace plays a significant role in energy use. Of course, the internal temperature setting of the refrigerator can have a significant effect on a refrigerator's annual energy use as can the temperature in the immediate area of the refrigerator. However, once the refrigerator's temperature is set it is less subject change to than the hour by hour changes that often occur with furnace thermostats.

Previous refrigerator studies indicate that a typical refrigerator operates such that it runs about 20 minutes and then is off for about 20 minutes. The 40-minute on-off cycle is fairly steady unless the resident places a warm object in the refrigerator to be cooled. Under normal conditions, the heat entering through the walls through conduction are fairly steady. The advantage of a two-hour measurement is that it encompasses three completed 40-minute cycles. Less than two hours means that there is a greatly increased chance of including more of an on or off cycle and obtaining a larger error in the estimated usage.

One surprise from previous studies was the large number of models that appear to operate all the time. When the operation exceeds 90 percent, it is most likely that the Freon charge is low or the internal temperature sensor is not operating correctly. Ideally, a refrigerator should operate about 50 percent of the time so that it will have sufficient additional cooling capacity to provide heat removal during periods of hot, humid summer weather.

**Data Collection**

This study is based on both results of measurement data recorded in the field by the program auditors and statistical study of the data. The study concludes with some generalization of the findings.

**Data Analysis**

There are two fundamental pieces of data used in this analysis, the wattage when running and the average hourly consumption. Previous programs have relied upon selection criteria using only average hourly consumption converted to annual energy use. First we will review the observed wattage when running. Second we will examine the average hourly consumption. Third we will look at the ration of the two which corresponds to the average running time. Finally we will examine a scatter plot of the two pieces of data to study the interaction of the two.

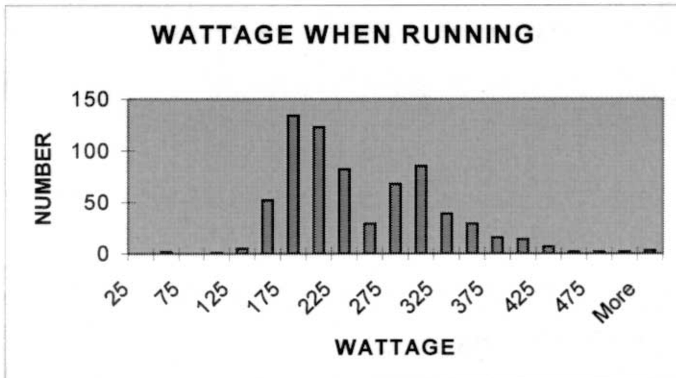


Figure 1. Observed wattage with refrigerator running.

Review of the wattage measurement data from this study in Figure 1, indicates few models with a wattage less than 140 watts and few above 400 watts. The valley in the observed distribution of the wattage from 220 watts to 260 watts is a strong feature of the data. The strong peak in the data near 275 watts could indicate a shift in values from 250 watts up to 275 watts. However, as will be discussed later, this is unlikely because it would have implied many more models operating at or near 100 percent running time.

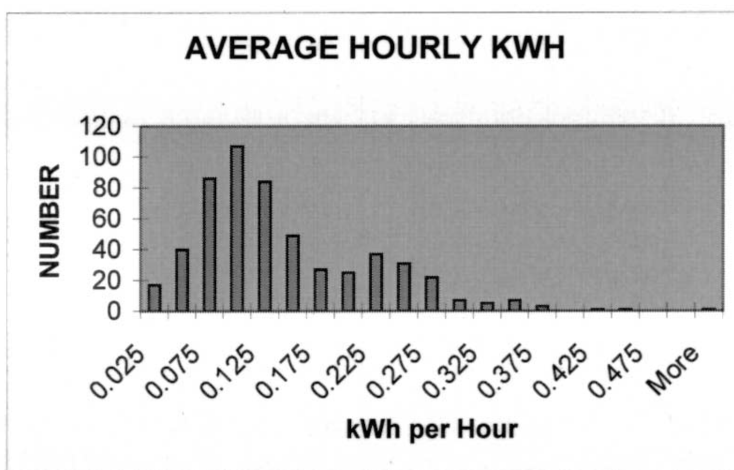


Figure 2. Average kWh per hour from a two-hour reading.

The data in Figure 2 indicates the distribution of electrical energy use usage in kWh per hour. The kWh measurement over the approximate two-hour measurement period was divided by the measurement time in hours to obtain the use per hour. Multiply by the hours per year (8,760) to obtain the annual energy usage. Analysis of eight-day refrigerator electrical energy measurements from the Chicago Housing Authority study in 10-minute intervals indicates an approximate 20 percent error in the annual usage with an additional error associated with extreme hot weather conditions. For the refrigerators measured in this study there is a decrease in the number of refrigerator measurements at 0.175 kWh/hr near the selection criteria cutoff of 0.150 kWh/hr (1,300 kWh/yr.) with an excess of measurements near 0.230 kWh/hr (2,000 kWh/yr.). As will be discussed later, the shift to higher usage is concentrated in the models with higher recorded operating wattages.

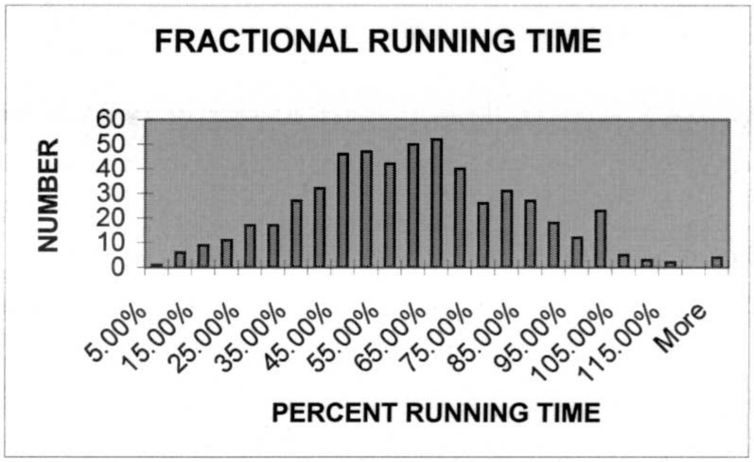


Figure 3. Estimated Refrigerator Fractional Run Time or Capacity Factor.

Figure 3 shows the distribution of percentage running time or what we shall call Capacity Factor. The distribution is generally a bell shaped curve with the major of the refrigerators from about 30 percent to about 85 percent. Previous studies have indicated a more typical range is from 30 percent to 70 percent with a median of 50 percent. The current sample appears to have an excess number of refrigerators operating at higher capacity factor. One possible explanation is that many measurement were taken during periods of hot, humid summer weather when the refrigerator had to operate for longer periods to compensate for the higher heat loads. From the auditors reading date, we believe this not to be the case. Another possibility is the prominence of elevated temperatures in low-income housing often associated with the elderly. The most likely explanation is that the current refrigerator replacement program was successful in locating refrigerators that were in poor operating condition.

For replacement candidates with a measured operating wattage greater than 250 watts, the median wattage is approximately 300 watts. Replacement with an energy efficient Energy Star model that operates near 150 watts implies a potential peak demand savings of 150 watts at time of system peak demand during hot humid summer weather when the refrigerator is running virtually all of the time. If the new Energy Star model has a capacity factor of 67 % at time of system peak demand, the weighted peak savings would be greater or nearly 200 watts. That is, the refrigerator that was replaced operated at 300 watts all the time and the new Energy Star model operates at 150 watts 67% of the time or 100 watts on average.

When the refrigerator is unplugged and then reconnected after being plugged into the wattmeter, although the refrigerator may want to resume operation, the freon needs to condense or the interior heat needs to build up and so some time passes, usually several minutes before operation begins. When the compressor starts, the initial start up wattage is higher than the steady state value as the compressor works against a higher load of uncompressed freon. The wattage falls slowly by about 10 or 20 watts to the final steady state value. If the refrigerator is in good operating condition, the wattage reading will be stead and slowly falling. Older models with poor bearings will have fluctuating wattage readings that slowly fall but have large fluctuation making steady state determination questionable. It should be expected that wattage estimates can have an error of up to 20 watts for older models and if the reading is recorded before steady state is attained.

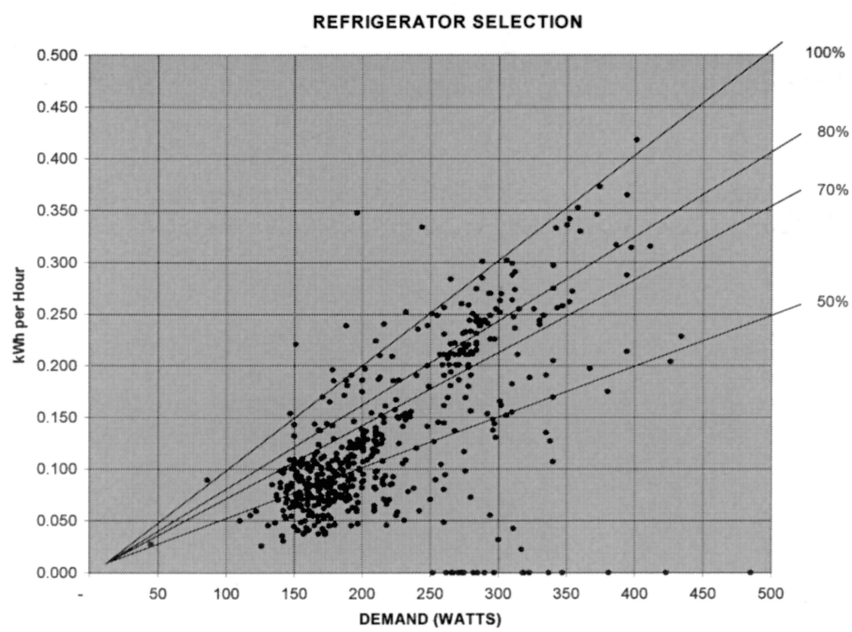


Figure 4. Refrigerator Selection Criteria Demand verses Usage.

The scatter plot in figure 4 indicates models with 100% run time along the upper edge of values. Notice the models that lie just below the 100% run time line. While many models fall on the line, there are a number of models ranging up to 20 watts above the 100% operating time line. These are probably models with wide fluctuations in the operating wattage or ones where the recorded operating wattage had not yet reached its asymptotic value.

Another feature of the collection of actual data is the effect of the lag between initial reconnection and the start of the refrigerator compressor operation. If it takes 6 minutes before operation begins after the reconnection, there may be 5% of a 2-hour measurement time when the refrigerator was incapable of operation. If this was a model with a bad temperature sensor that usually runs all the time, the observed percent run time over the 2 hour measurement time including the 6 minute down time would be 95% not the potential 100%. An estimated average hourly consumption of 0.200 kWh/hr could be low by 0.010 kWh/hr. or 5%. Several of the data points that fall just below the 100% run time line could be just this effect.

Another explanation for data points just below the 100% run time line is the starting backpressure in the compressor. When the compressor first starts, it requires a higher wattage or more power to get started. When observing the wattage draw of a refrigerator after the initial start up, the wattage will fall slowly over a 5-minute period to a lower steady state value usually about 10 or 20 watts below the initial start up value. If the initial start up wattage is recorded and the refrigerator runs all the time, the apparent percent running time will be low by about 5 or 10 percent. So some of the observed percent running times near but just under 100% are probably due to recording the initial start up wattage rather than the final steady state operating wattage.

Data points with an apparent run time of greater than 100% are probably bad data reading or estimated measurement times that are less than actual so the calculated average hourly usage is too large. However, these data points with greater than 100% running time are useful. Since we know that running times can not be greater than 100%, these points allow us to make an estimate of probably measurement error. The error can be estimated by determining how far a data point must be moved to bring it back to the 100% line. Typical values are 20 watts for the wattage measurement and 0.020 kWh/hr for the usage. The relatively few number of data points at greater than 100% running time provides some confidence in the accuracy to the auditor data.

An unconscious bias toward recording the wattage reading when above the 250-watt replacement cutoff could account for the deficit of readings from 240 watts to 250 watts. However, if that were the case an the steady state reading should have been lower, then the percent running time would be higher leading to even more high run time measurements than observed.

Another benefit resulting from the replacement of older refrigerator models is that many older models were not power factor corrected. The resulting larger current draw contributed to increased current draw on the system with increased line losses at time of system peak demand. It was just such a problem with older room air conditioner models that contributed to under ground power cable over heating that lead to the distribution problems in the late 1960's in New York City. Newer high efficiency refrigerators with better power factors result in lower line currents and correspondingly lower distribution line losses. The lower line losses result in increased system reliability.

Another feature of the data is the number of refrigerators with an apparent operating wattage of great than 350 watts. In particular there appear to be an excess of about eight refrigerators near 400 watts. A refrigerator model with automatic defrost has a heating element. These are typically 400 watts. Typical operation is for the automatic defrost cycle to initiate operation after 8 hours of run time. With a 50 percent run time characteristic of a typical refrigerator, the auto defrost cycle begins about once every 16 hours. A typical cycle is to heat for about 12 minutes and ten be in a controlled off mode for about 20 minutes before a new compressor cycle begins. The audit that records a running wattage near 400 watts should listening closely to determine if the refrigerator is actually running. If the auto defrost is on, the auditor will likely hear little popping sounds from the defrost cracking the ice. A second reading taken when the refrigerator is clearly running taken about 5 minutes after the first reading would verify if the running wattage recorded was truly the 400-watt value.

Another feature of the data is the few models with wattage reading less than 130 watts. These should be checked to assure they do not represent a measurement of the anti-sweat heater running when the refrigerator compressor is not operating. As above, the auditor should listen to the refrigerator to assure that the refrigerator is actually operating. If the door is not completely closed or the interior light switch is broken, the interior light could be on. Two 40-watt light bulbs and a 20 or 40 watt anti-sweat heater could account for faulty readings from 20 watts up to 120 watts.

One advantage of a two hour measurement time compared to a four hour measurement is that it is only half as likely to include a portion of the defrost cycle. A four hour measurement time implies that nearly 25% of the measurements would include a portion of the auto defrost cycle which will introduce an error into the measurement. A two hour measure is only 12 ½% likely to include a portion of the defrost cycle so the consistency of the estimate is greater from measurement to measurement.

## Findings

The key findings from the study are summarized in this subsection.

## Replacement Rate

Of 548 complete measurements, 206 (38%) were identified for replacement and 342 (62%) fell within the acceptance range.

## Energy Savings

The average estimated annual kWh for the entire 548 measurement sample was 1,132 kWh/yr. For the 206 identified for replacement, the average estimated usage was 1,811 kWh/yr. For the 342 units that were retained, the average estimated usage was 723 kWh/yr. The average annual kWh saved through replacement of the targeted units with ENERGY STAR units with an average annual usage of 580 kWh/yr. results in an average annual savings of about 1,230 kWh/yr. The estimate of an annual energy savings of 1,230 kWh/yr. may be taken as a good rough estimate. Though one needs to be careful reading too much into an estimate that comes from only one season of the year, does not measure the temperature delta across the refrigerator wall, and does not monitor for more than two hours, the difference between the measured results for the refrigerators identified for replacement and those identified for retention is sufficiently great that even if the estimate was off by 25 percent, the savings from replacement with Energy Star units would be cost-effective.

## Demand Savings

The selection criteria used in this study also provide for an estimated reduction in peak load demand during hot, humid summer weather of 300 watts per units.

## Opportunity Savings

The selection criteria to remove units that operate at more than 70% running time provides for early replacement of units in poor repair. If these units are not replaced under the current program, the low-income household is likely to replace it within the next few years with inefficient unit purchased from a used appliance store. Early replacement assures the low-income family future utility savings they might not have received.

### Overall Effects

This study of the data used for refrigerator replacement shows several unusual features. The data tends to gather in two clusters. There is a lower usage cluster with running wattage between 140 watts and 220 watts with an annual average usage between 1000 kWh (0.110 kWh/hr) and 500 kWh (0.600 kWh/hr). There is a second higher usage cluster with running wattage between 260 watts and 300 watts with an annual average usage between 1,700 kWh (0.200 kWh/hr) and 2,200 kWh (0.250 kWh/hr). For high wattage models there is an excess of data at high run times of greater than 70% corresponding to high annual usage. For lower wattage models, there is a cluster near run times of about 50%. Replacement of the high usage, high wattage models with high run times provide a substantial benefit to low-income customers.

### Comparisons with previous Studies

The results for this program indicate an anomoulous large deficit of models with an operating wattage near 250 watts. Since this was indicated on the recording form as one of the selection criteria, auditors might have exhibited a tendency to record data slightly below or slightly above 250 watts in order to make a clear distinction. The concentration of data around 275 watts and with an average hourly usage of 0.225 kWh/hr (2,000 kWh/yr.) argues against a simple bias away from 250 watts. The lack of measurements above 250 watts with a capacity factor near 50% indicates that measurements would have had to be shifted to higher capacity factors. Measurement during hot, humid summer weather conditions could account for a possible shift to higher capacity factors.

The lack of measurements from 230 to 250 watts could be explained by a tendency to record a wattage measurement that was low to assure that the refrigerator would not be removed. The concentration of data near 200 watts and 0.102 kWh/hr with a capacity factor of 60% could be explained if the wattage measurements were low. The kWh/hr would remain the same however the capacity factor would shift to the more typical value of 50%.

A more likely explanation is that the data is correct and indicates that the current selection criteria based on 250 watts is the appropriate value. Older inefficient models with poor insulating values required a larger compressor to maintain adequate cooling. They also tend to run more often. Newer models post the 1990 Federal Energy Efficiency Standards with rigid foam insulation require a smaller compressor that draws less than 250 watts and also runs less often.

The significant difference between the measurements below 250 watts and those above 250 watts indicates that the 250 cutoff for replacement is effective in identifying inefficient models from newer efficient models.

## Program Recommendations

Based on the results of our analysis of the data evaluated, we have the following suggestions to improve the Refrigerator Replacement program:

- Include and record additional visual selection including color such as Avocado, Brand such as Signature, model type such as Side-by-Side and features such as through the door ice or water.
- Record the initial and final measurement times to the minute rather than 15-minute increments.
- Repeat running wattage measurements if less than 100 watts (possible anti-sweat heater) or greater than 350 watts (possible auto defrost heater) but retain wattage cut off for replacement at 250 watts.
- Record the kitchen temperature to estimate impact on running time.
- Retain selection criteria to replace if greater than 70 percent running time.

## Acknowledgments

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