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Monitoring Refrigerator Energy Use: Simplifying the Methods

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Refrigerators use more energy than any other kitchen appliance. This fact is not surprising when one considers that they are operating to keep food at a safe temperature 24 hours a day, 365 days a year. In many low-income households that do not use electricity for space or water heating, refrigerators represent more than half the electricity consumed in one year. And if the refrigerator in a family's home is functioning poorly, the cost to the consumer can be enormous.

Discovering whether one's refrigerator is operating inefficiently can be a awesome task for a resident who only sees a monthly electric bill. Moreover, knowing when it makes economic sense to invest in the replacement of an existing refrigerator with a new one can be a challenge to almost anyone.

Appliance energy labels, of course, make the choice of a new refrigerator much easier than it once was, and the EPA-DOE Energy Star symbol simplifies matters further. But if one's refrigerator is not totally non-functional, it may be difficult to address the question of whether to buy a new energy efficient refrigerator to replace the operating existing unit.

The key piece of information that is usually missing is some approximate usage of the existing refrigerator. The 1993 Residential Energy Consumption Survey tells us that the average household consumes approximately 1386 kWh per year for refrigeration, but we know that averages tell us little about individual units. The rated usage of a refrigerator can provide a great deal of information, but we have found refrigerators that consume in excess of three and one-quarter times the rated usage. Moreover, we found that almost half of the refrigerators at two public housing authorities consumed more than 1.2 times the rated usage.

It would seem that the only way to acquire reasonably accurate information on individual refrigerators is to monitor them.

We have been involved in several refrigerator monitoring efforts in recent years and offer this article in order to pass on some of our experience and observations. We recognize that monitoring can serve different purposes. Precise measurement may be required for large shared savings programs; less precision may be acceptable for projects that are geared toward identifying power hogs that are operating poorly. Just as one would not want to use a sledgehammer to crack a nut, one should not use a more sophisticated - and costly - monitoring method than is needed.

In this article we will start by reporting some of the results from our measurements. We will concentrate on the results from monitoring at the Chicago Housing Authority (CHA) where we have the most extensive data. These results are compared to monitoring by another group of analysts. The CHA data enabled our exploration of alternative monitoring approaches that require less data acquisition time and expense. Two approaches are discussed here. We hope these methods are of use to other analysts looking at public housing and those trying to include refrigerators in weatherization programs or other energy efficiency programs.

Some Bottom Line Results

Let's start with the bottom line results. We found that the older refrigerators that were being used at the CHA were consuming 976 kWh per year on average for comparable units to the energy efficient refrigerators installed under a bulk purchase program created by the Department of Energy and the Consortium for Energy Efficiency. The energy efficient units consumed an average of 480 kWh per year. This savings of 496 kWh per year per unit that was replaced translated into a savings of approximately $570,000 in electricity bills when CHA pulled out 10,700 old refrigerators and installed the new Magic Chefs, model CTN1511AEW. Picture 1 shows one of the units being delivered to the Cabrini Rowhouse Development in Chicago.

Picture 1: CHA refrigerators being delivered

The per unit savings estimate that was found at CHA is about 9 percent less that the savings estimated for the New York City Housing Authority by researchers at Pacific Northwest National Laboratory (see R.G. Pratt and J.D. Miller: "The New York Power Authority's Energy-Efficient Refrigerator Program for the New York City Housing Authority - 1997 Savings Evaluation", PNNL-11990, September, 1998). In that study, the older refrigerators were found to consume an average of 963 kWh per year and the new replacement refrigerators were estimated to consume 420 kWh per year on average. With the exception of the low usage estimate for the replacement units in the New York study, it is remarkable that the two studies found such similar results.

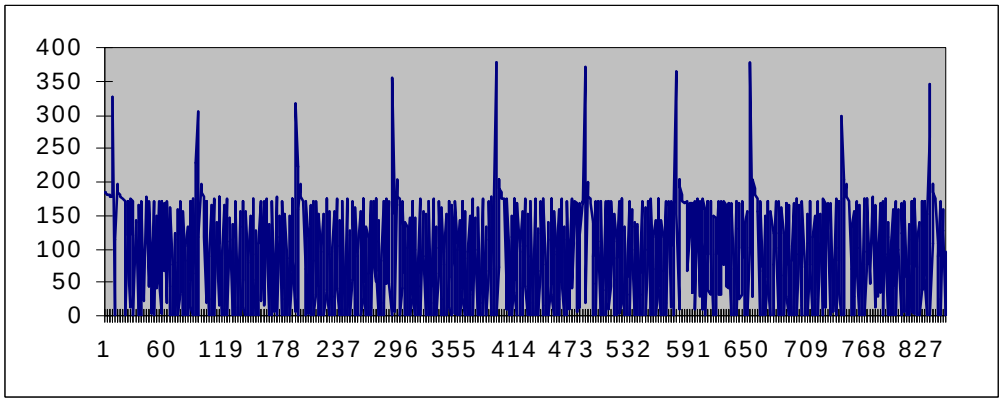
Our estimates included the impact of kitchen temperature and the food compartment temperature within the refrigerator. Not surprisingly, the temperature delta matters a great deal. We found that at normal building temperatures each one degree-Fahrenheit increase in the temperature differential across the refrigerator wall leads on average to a 2.26 percent increase in electricity consumption of a unit above its rated usage. We monitored units at different times of the year (during each season), and found that the temperature delta captured the significant changes through the year.

The primary monitoring methods used for the CHA analysis relied on three data loggers, shown in Picture 2. We logged one week of temperatures inside the refrigerator's food compartment and near the refrigerator in the kitchen - taking care not to situate the logger too close to the stove or other heat generating appliance. These measurements were made using Onset's Optic StowAway

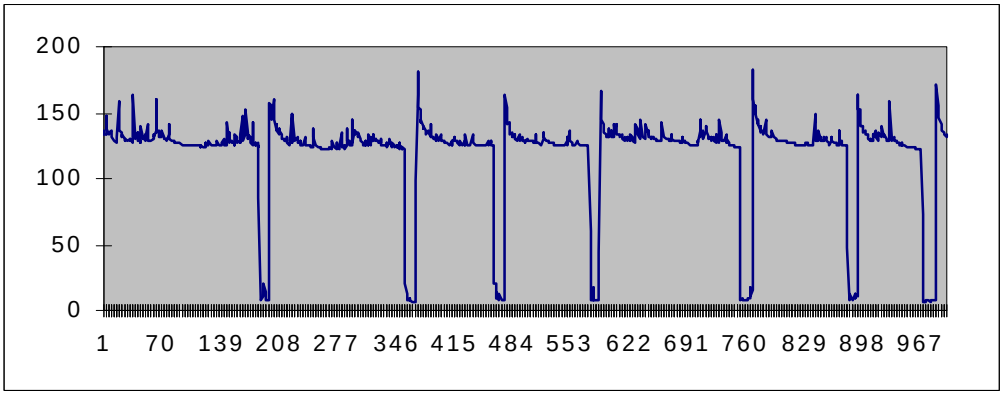
Picture 2: Onset Temperature and Brultech KWH Dataloggers

Temp loggers, which are waterproof and could withstand spills of milk, jelly, or yogurt. The devices cost about $120 per logger and need a special infrared downloading device that costs an additional $130. We also logged ten minute interval electricity usage of the refrigerator for the same period of time. For this measurement, we used Brultech's KWH Data Logger that sold at the time for about $250 per unit and required software and cables costing $165.

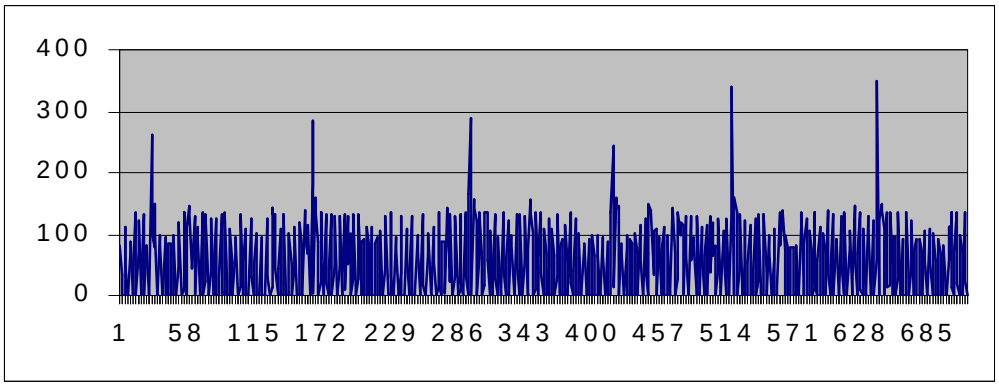
Below we show three graphs of the electricity consumption for three units monitored. Graph 1 is of a properly functioning refrigerator within the CHA stock prior to the replacement program. One notices the stable on-off signature with regular spike indicating the defrost cycle. Graph 2 is a poorly operating frost-free model which was using slightly more than 1.5 times its rated usage level and not keeping food at proper



Graph 1: Watts used for each 10 minute time interval during the monitoring of a properly functioning older refrigerator



Graph 2: Watts used for each 10 minute interval during the monitoring of a poorly functioning older refrigerator

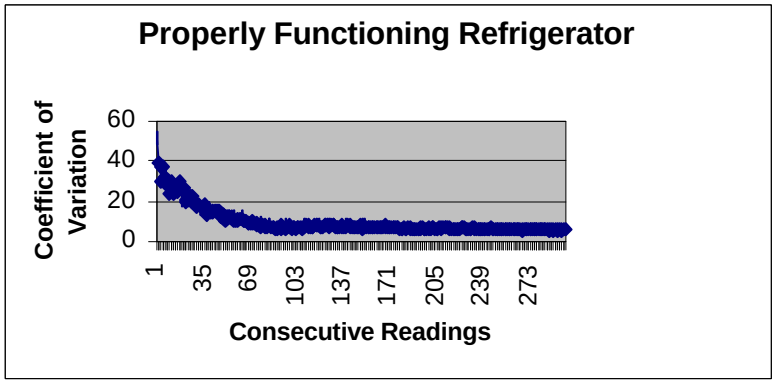


Graph 3: Watts used for each 10 minute time interval during the monitoring of a new energy efficient refrigerator

temperatures. Graph 3 shows the usage pattern of one of the energy efficient replacement units. This unit has a similar signature as in the first graph, but the cycling is at a lower wattage level during the on-off cooling periods, the off periods are more pronounced, and the spikes of the defrost cycle are lower.

How Long Should One Monitor?

With the 10 minute interval consumption data, we wanted to ask the question: how long should one monitor to get good results? Of course, the notion of "good results" is different with different objectives. One may want to monitor for several weeks under varying temperature conditions to obtain precise results for the operation of a single refrigerator model. But to find an accurate estimate of the average for a varied stock of refrigerators in a housing authority's inventory, considerably less monitoring time is required. Also, to identify which refrigerators are operating at wide variance from their rated levels, one needs a fairly short monitoring period.



Graph 4

We came to some conclusions about the monitoring periods required by analyzing the ten-minute interval data that was collected in our CHA monitoring. Graph 4 shows the coefficients of variations (the standard deviation of a sample divided by the sample's mean) for the refrigerator displayed in the first graph above as we increase the number of consecutive observations. To develop this graph, we started by taking 100 random samples of two consecutive readings from the week's worth of information collected. We then calculated the mean and standard deviation of the 100 samples. We then took 100 random samples of three consecutive readings and again calculated the standard deviation and mean. We continued bootstrapping random samples with longer and longer consecutive readings until we had three hundred consecutive observations. The graph is a plot of the coefficient of variations for the samples of 2 through 300 consecutive observations. The graph shows that the coefficient of variation settles down rather quickly. One sees that in this graph after less than

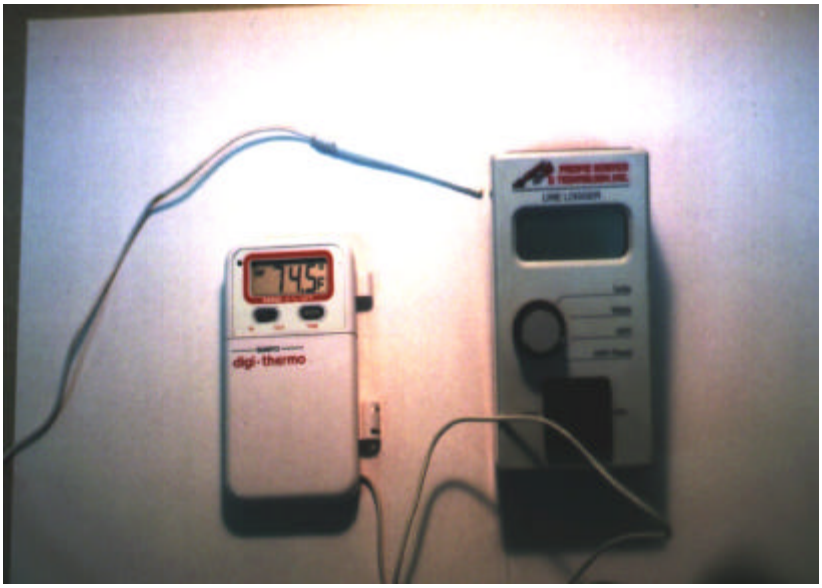
100 consecutive observations the coefficient of variation stabilizes.

The pattern shown in this graph was found repeatedly in analyzing the 10 minute interval data for the refrigerators sampled. The coefficients of variation consistently stabilized to closely approximate the full sample after less than 200 consecutive observations. This would suggest that one can achieve a reasonable estimate of the electricity usage of a refrigerator with less than two day's monitoring (because 48 hours would be 288 consecutive 10 minute periods).

To be sure, two day's monitoring of one unit could be at large variance with the average usage of that unit over the year. However, if one is taking a sizeable sampling of the stock of refrigerators in a housing authority's inventory, any one aberration will have a limited impact on the mean for the entire sample of refrigerators. This is a straightforward application of the law of large numbers. In the case of our monitoring for the CHA, we sampled 150 units.

Monitoring for Less

If one is able to develop a good estimate of the average electricity consumption for a stock of refrigerators by sampling two-day's worth of consumption for each unit, then one can substantially reduce the cost of monitoring. The time required for measurements is substantially reduced. Also one can use simple watt meters (line loggers) to monitor the cumulative usage over the two day period rather than the electricity usage profile throughout the sampling period.



Picture 3: Inexpensive Digital Thermometer and PST Line Logger

Picture 3 shows the type of equipment that can be used for this less expensive monitor. Though we often continued to use the temperature dataloggers to view the profile of the temperature in the food compartment and the apartment, we also used a digital thermometer that can be purchased for under $50 at most hardware stores. When we used the digital thermometers, we measured the food compartment and apartment temperature at the start and at the conclusion of the monitoring. Many digital thermometers record the minimum and maximum temperatures between resetting. At times we left the thermometers in the refrigerators through the monitoring period to look for substantial temperature swings.

The line logger shown in Picture 3 sells for under $200. It plugs into an electrical wall outlet and the refrigerator plugs into it. The line logger accumulates the kilowatt-hours over the period of

monitoring. It is important with these devices to accurately record the time that monitoring begins and the time that it ends since time is not recorded in the logger.

As with the monitoring that was done for the CHA, it is important to sample a sizeable number of refrigerators in the inventory. However, with two day monitoring periods one can move a line logger around to many locations in several weeks. Our monitoring at the Pittsburgh Housing Authority used this method with five line loggers and collected data on 35 refrigerators in four weeks.

Most larger housing authorities are interested in measuring appliance energy usage in order to define a baseline average electricity consumption for a large scale replacement with energy efficient units. This is not the only rationale for monitoring. One may wish to identify poor performing refrigerators with an eye to selective replacement. Weatherization or other community energy efficient programs may also want to identify refrigerators that are operating substantially above the rated usage.

Graph 4 provides us with insights into monitoring for bad refrigerators. One notices the steep decline in the coefficient of variation as the number of consecutive observations increases. If a unit is running constantly because it has lost most of its refrigerant or has a malfunctioning compressor, the refrigerator will run constantly rather than cycle on and off. This can be identified quite quickly. In particular, in less than a two hour period one should be able to determine if a refrigerator is cycling or not.

Typical residential audits take two hours or more. In such an audit, a line logger like the one shown in Picture 3 can be used to monitor a refrigerator's performance. While two hours would not be adequate to achieve great accuracy in estimating the expected yearly electricity consumption, it is sufficient to determine if the refrigerator is operating 100 percent of the time

Summing Up

The findings reported above suggest several things. First - and most importantly - the savings from replacing older refrigerators can be substantial. In both the Chicago and New York City housing authorities, replacing the existing units cut electricity usage by over 50 percent. Second, developing an average usage for the existing stock of refrigerators does not need to be a long and expensive task. In fact, it can be completed by maintenance staff and thus reduce dependence on information collected by energy service company staff or other outside contractors. Finally, it is possible to identify the poor performing units that can be made special targets for immediate replacement.

We conclude with a paraphrase of the founder of Faber College from the movie "Animal House", measurement is good. To this we add that good measurement need not be costly.