Refrigerator Monitoring, A Sequel

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by Larry Kinney

How briefly can you monitor refrigerator energy use and still get valid results? *Home Energy* takes another look at this timely topic.

Utility or public housing programs that replace inefficient refrigerators with more efficient models clearly save energy (see "Monitoring Refrigerator Energy Usage," *HE,* May/June '00, p. 32). But, how best to identify poor performers that need replacing is not as simple a question as it may first appear to be. The results of short-term monitoring of any given refrigerator can be affected by such factors as ambient temperature, control settings, the refrigerator's condition, food-loading patterns, and door openings. Even for simple replace/don't replace decisions, I believe that testing of automatic-defrost refrigerators should be conducted for well over two hours. This recommendation is based on extensive testing both in the field and in a laboratory test chamber, using a dedicated 11-channel data logger that was specially designed for testing refrigerators.

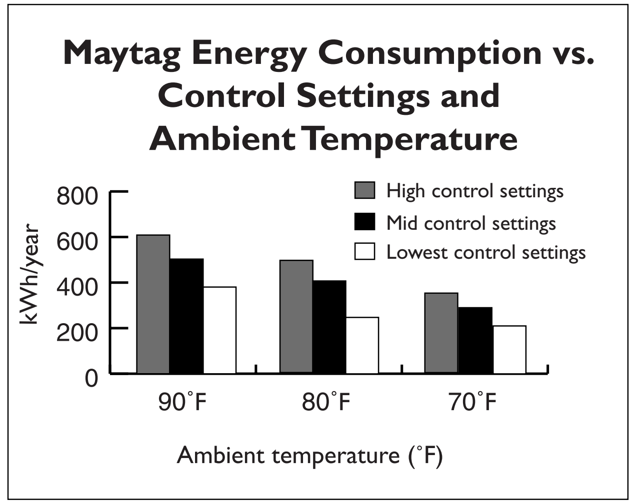
To obtain a refrigerator's annual energy use rating, DOE regulations require manufacturers to monitor automatic-defrost refrigerators from the beginning of one defrost cycle to the beginning of the next. Testing is conducted on empty refrigerators with closed doors at an ambient temperature of 90˚F for this "natural" period. The length of time between defrost cycles is typically 12 hours of compressor run time for many models that are more than five years old. Compressor run times per unit of real time depend on a number of factors. These include:

- The condition of the refrigerator's thermal envelope and cooling system.
- The difference in temperature between the inside and outside of the refrigerated spaces, which in turn is a function of control settings and ambi-

ent temperature. (Defrost cycles for an energy-efficient Maytag unit occur at 52-hour intervals at 65˚F and at 28-hour intervals at 80˚F. These figures directly relate to differences in annual consumption).
- Food-loading patterns and door openings.

In the field, however, a long monitoring period is frequently neither desirable nor necessary. For example, a refrigerator replacement program's guidelines may specify that all replacement candidates must exceed a specific threshold of consumption, so that all replacements surpass some specified benefit-to-cost ratio. In many cases, this decision may be made simply by inspecting a given unit—because the DOE rating for the model may be substantially higher than the agency's threshold, the model of refrigerator may have been tested before, or major mechanical problems may be causing excess consumption. However, if no history is available or the unit is not in the AHAM directory, and if there is no evidence from the customer—or the unit itself—of malfunction, it may be useful to run a short-term test to determine performance.

Now, how long should a short-term test last? That question needs to be broken down into two key questions. How long of a testing period is necessary to draw an inference that is sufficiently accurate to make a valid replacement decision? How long of a testing period is necessary to provide information useful in performing an evaluation of savings achieved by a refrigerator replacement program? These questions are similar but distinct, since making a binary replace/don't replace call in most cases will require less accuracy than deriving performance data for an evaluation. However, to answer either question it is imperative to estimate the errors that are associated with the time period of a test.



LARRY KINNEY

Figure 1. Control settings have a very powerful effect on energy consumption that needs to be taken into account in refrigerator program execution and consumer education. Rational control settings can save lots of energy.

LARRY KINNEY

Glen Lewis, a researcher with the Synertech Systems Corporation, monitors the performance of a small refrigerator of the kind found in many dorm rooms. Such units are poorly insulated and appallingly inefficient (this one uses almost 200 kWh/year).

Ambient temperature strongly affects monitoring results, and even relatively long-term tests of less duration than a year cannot account for this factor completely. To correct for temperature, the best strategy is to:

1. Measure the ambient temperature during the period of the short-term test.
2. Measure the consumption of the unit (or similar units) under a range of ambient temperatures, holding other variables as constant as possible.
3. Measure—or estimate as well as possible—the annual ambient temperature immediately adjacent to the refrigerator. If the average ambient temperature during the period of measurement is substantially different from the average expected over a year, I use a correction factor of 2.5% per ˚F (see Figure 1).

I arrived at this correction factor after gathering a great deal of chamber data at constant ambient temperatures and control settings for dozens of refrigerators, both old and new. The data presented below reflect tests on a 15 ft^3 Maytag unit (model CTL1511AEW, a model frequently employed in refrigerator replacement programs). I have found that I am able to obtain repeatable estimates of annual performance that vary by less than 1%, based on monitoring a unit from the beginning of one defrost period to the beginning of the next.

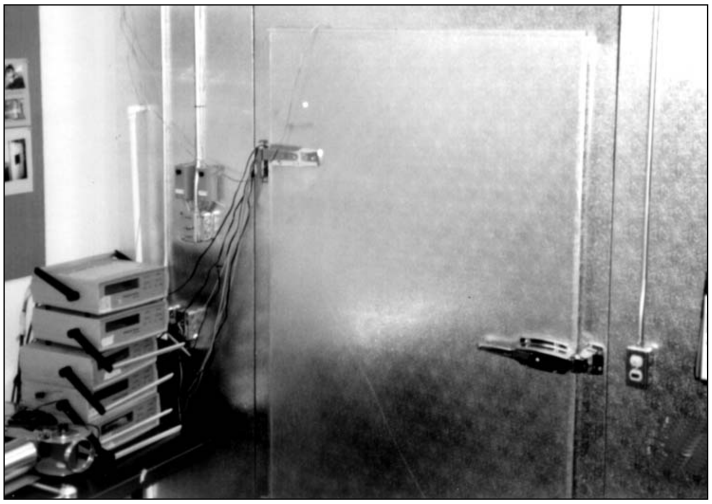
I turned next to the question of shortening the monitoring period. In

Table 1. Short-Term Testing Analysis

Interval (minutes)	Standard Deviation Total	Tests Within 10%	Standard Deviation Mid	Mid Tests Within 10%
60	94.17	17.5%	73.7	18.3%
90	76.08	25.9%	55.3	27.8%
120	61.1	34.5%	39.1	37.4%
180	34.3	89.4%	19.1	97.2%

order to find out how short-term is too short-term, I ran the refrigerator for several weeks at constant ambient temperature and control settings. The doors were kept shut and the refrigerator was not loaded, just as with the DOE test. Each minute, the R-100 data logger wrote a time series data record of the date; time; energy in watt-hours (Wh) consumed over the previous interval; power factor; run time in seconds of the defrost heater; and temperatures of the fresh-food compartment, the freezer compartment, and the test chamber itself.

The controls were set at 2 of 7 for the refrigerator, and 3 of 5 for the freezer, the optimal settings to maintain energy efficiency and fresh food. The chamber temperature averaged 80˚F over the interval (with a standard deviation of 1.03˚F); the freezer temperature averaged 4˚F; and the refrigerator temperature averaged 43˚F over the period of the test.



LARRY KINNEY

This environmental test chamber is quite well-insulated and has heating and cooling equipment that maintains the set temperature to within 1 degree F. Since there are many factors in the field that affect short-term performance, it is useful to employ a chamber to limit the number of free variables.

The refrigerator consumed 1,161 Wh over the 1,668 minutes (27.8 hours) of the test, measured from the beginning of one defrost period to the beginning of the next. This corresponded to a consumption of 366 kWh per year. The defroster heater drew 400 watts and was on for 5.32 minutes. This supplied 120 Btu of heat, which raised the freezer temperature to above freezing for a short period.

I then examined the data to see how accurate shorter-term tests would have been. I estimated annual performance from “measurements” taken at every 60-minute interval, every 90-minute interval, every 120-minute interval, and every 180-minute interval over the entire period. For each of the resulting 6,672 measurements, I expressed the percentage difference between the estimate and the actual measurements (see Table 1).

Note that the shorter-term tests show very large standard deviations. Only 17.5% of the 60-minute tests were within 10% of the actual figure—an error band that most program operators would prefer not to see exceeded for refrigerators submitted to field testing. However, the errors become less egregious as the time interval exceeds two hours, particularly in the periods not affected by the defrost cycle.

For the mid tests (those not influenced by the defrost cycle), the estimates averaged 4% low for each of the intervals, according to these chamber data. However, under field conditions, with door openings and food being loaded into the refrigerator, latent loads due to increased humidity in the refrigerator are much higher than in the chamber with refrigerator doors kept shut. This means that for a given difference in temperature between the cooled compartments of the refrigerator and ambient, the compressor will run more often in the field to remove moisture,

LARRY KINNEY

Monitoring the SERP refrigerator manufactured by Whirlpool. This unit auto defrosts via a series of very short-term defrost periods rather than one long one, which is the routine with most other household refrigerators.

LARRY KINNEY

This R-100 data logger was designed to monitor the performance of refrigerators. It tracks 11 parameters and writes a time series data record at the interval chosen by the user, from one to sixty minutes. Its memory records over 15,000 data records before the newest data begins to overwrite the oldest.

LARRY KINNEY

There are two sensors on the end of the wire; one is an electronic device that measures temperature, the other light. Light levels on the inside of refrigerators do indeed attenuate substantially when doors close, a fact that is recorded by the data logger in the "door closed" column of a spread sheet. The handheld radiometer can be used to measure surface temperatures virtually instantaneously.

causing the time interval between defrost periods to be shorter. In addition, the defrost period will be longer, owing to the need to remove more ice. Based on a number of tests, I have concluded that the energy consequences of the defroster—both the use of the electric-resistance heater and the additional compressor run to remove its heat—increase the overall energy used by refrigerators by about 8% over an equivalent manual model.

Combination temperature/light probe installed in a refrigerator's fresh food compartment. The time for setting up and verifying functioning of the instrumentation averages 15 minutes; data download and equipment stowage aver-

Short-term tests are more likely to encounter defrost periods in the field than in the chamber. Since these defrost periods will be longer (typically 12 minutes instead of the 6 minutes measured in the chamber), they will have an even more profound overall effect than those illustrated by the chamber data. On the other hand, since the compressor will run more often, short-term tests that avoid the defrost cycle may be somewhat more accurate.

Therefore, in general, the best practice for refrigerators that have automatic defrost should be to test for well over two hours, preferably using a device that senses defrost cycles. The sensing part is usually simple, since the power factor during defrost approaches unity (compressor motors typically run from 0.5 to 0.7 power factor, although some new units have power factor compensating circuitry that yields net power factors greater than 0.9). Further, refrigerators typically use a 400W–600W electric-resistance heater to perform the defrosting function, in contrast with a compressor motor that may use only 150 watts or so.

If data are collected over the defrost period, either the short-term test should be conducted again, beginning an hour after the defrost period, or, preferably, the test should be continued through the next day or two. The ideal is to use as many periods as is practical (from the start of a defrost period to the start of the next), and then normalize for a year's consumption. For manual defrost units, a two-hour test should be satisfactory for a determination on replacement.

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