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Japanese Refrigerators
A Field Performance Analysis
Summary Report

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Bonneville Power Administration Perspective

JAPANESE REFRIGERATORS: A FIELD PERFORMANCE ANALYSIS SUMMARY REPORT

Project Objective and Background

The Pacific Northwest Electric Power Planning and Conservation Act, signed into law December 5, 1980, mandated regionwide energy conservation practices. Under the act, BPA must identify and implement cost-effective electric energy options and programs for the Pacific Northwest. The Residential Technology Section in the Division of Resource Management supports current residential energy conservation programs and designs and conducts various research and development projects, of which this project is one.

Laboratory test procedures used by the Japanese had shown their refrigerators to be about 50 percent more efficient than American-made refrigerators. A previous BPA study tested 12 Japanese refrigerators according to the U.S. DOE laboratory procedure. When tested to the DOE procedure, Japanese refrigerators used about 43 percent more energy than when tested by the Japanese procedure.

This study compared in-home energy use of 12 Japanese refrigerators identical to those in the laboratory test to both the Japanese and U.S. DOE laboratory tests.

Project Approach

To test in-home energy use, the 12 Japanese refrigerators were placed in the homes of BPA employees in the Portland/Vancouver area and used as the primary refrigerator for 18 months.

Data was recorded manually by homeowners and included:

- cumulative energy use
- cumulative door openings
- winter thermostat setting
- number of occupants at the beginning of the test
- any special applicable events

All collected data was entered into a computer spreadsheet and analyzed to produce this report.

Conclusions

Japanese refrigerators use about 43 percent more energy with the U.S. DOE laboratory test than with the Japanese laboratory test. In the Portland/Vancouver area, the in-home energy use for refrigerators without anti-sweat switches was 15 percent higher than predicted by the Japanese test procedure and 25 percent lower than predicted by the DOE test procedure. Other studies also suggest that the DOE test procedure tends to overpredict in-home energy use. The refrigerators with anti-sweat switches used 2 to 13 percent more energy than the DOE test.

The DOE test procedure had a higher correlation with in-home energy use than the Japanese procedure.

As shown in other studies, this study also had a low correlation of energy use with the number of door openings.

Although kitchen temperature was not recorded for most of the study, the peak monthly energy use occurred in July and August and the peak weekly energy use often occurred during these months. This suggests that refrigerator energy use is sensitive to kitchen temperature. Other studies have shown a high correlation of energy use with kitchen temperature. There was also a relatively high correlation of energy use with outside temperature.

A companion document, Japanese Refrigerators: A Field Data Analysis Final Report, contains a complete analysis of the data.

(FOR ADDITIONAL INFORMATION, contact Roy Reinhart at the Residential Technology Section, Bonneville Power Administration, P.O. Box 3621, Portland, Oregon 97208-3621.)

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BACKGROUND

Society generally expects Japanese refrigerators to be more energy efficient than their American-made counterparts. With increasing attention being focused on appliance energy efficiency, research into operating characteristics of Japanese refrigerators has gained importance.

Other projects report the monitored energy use of certain models of Japanese refrigerators.^{1,2} In addition, laboratory tests determined energy consumption of certain refrigerators under controlled conditions.³

In 1987, Bonneville Power Administration (BPA) undertook a project to measure and analyze the energy consumption of 12 Japanese-made refrigerators in the Portland-Vancouver metropolitan area. This project's purpose was to collect field data on certain models and compare with that collected in other projects and laboratory tests.

Japanese energy consumption figures fall 30-40% below those of DOE.³ This energy savings, if real, could substantially cut baseload power for utilities. Determining typical refrigerator energy use patterns and which environmental factors effect them helps utilities to forecast demand.

TECHNICAL APPROACH

This report presents and analyzes roughly 18 months of field data on 12 Japanese refrigerators, including 3 matched pairs. Selected Bonneville Power Administration (BPA) employees used these refrigerators in Portland OR and Vancouver WA.

Manual data collection occurred roughly every week providing:

- Cumulative energy use.
- Cumulative door openings.
- Thermostat set point (winter only).
- Number of occupants (stated at beginning of test).
- Record of any special applicable events.

Actual data collection intervals ranged from 4 days to several weeks or even months. Data normalization to 7-day weeks eliminated this source of error.

Refer to "Japanese Refrigerators Field Test Data Analysis" by Peter E. Nelson⁶ for a detailed discussion of the data compilation methods used.

This study determines weekly, monthly and annual average and peak energy consumption of Japanese refrigerators in 'real world' settings. Comparisons relate these figures to tested values from

DOE and Japanese manufacturers. Since DOE and Japanese test procedures and outcomes differ drastically, relationships between these and actual energy usage appear useful. With two different test standards, comparison of labeled energy consumption by consumers becomes futile.

Objectives for this study include determining accuracy of DOE and Japanese test results for predicting field energy use. Also, consideration of environmental conditions should provide more accurate prediction equations.

RESULTS

Comparisons of field results with DOE and Japanese (Japan) test results were done. Japanese tests measure energy consumption with a food load, door openings, and two ambient temperatures. DOE tests measure energy consumption at 90 degrees F ambient temperature with no door openings or food load. Each test intends to provide the consumer with a means of comparing energy consumption between different units, though results of the two tests on the same refrigerator differ substantially. Alan Meier provides more details on these tests in his report "Energy Use Test Procedures for Appliances: A Case Study of Japanese Refrigerators".³

Data analysis produced the following results:

1. Multivariate regression of Department of Energy (DOE) test results and outside temperature with energy consumption gives this equation.

$$\text{Field KWH/day} = (.00323 * \text{DOE}) + (.0183 * \text{Out.Temp.}) - 1.900$$

$$r^2 = 0.87$$

Out.Temp. is average daily outside temperature in degrees F.
DOE is DOE predicted energy use in KWH/yr.

Though results would most likely be more accurate with true kitchen ambient temperatures, outside temperatures allow utilities to do predictions without such intensive monitoring.

2. Regressing average annual energy consumption with Department of Energy (DOE) test results gives a high r^2 of 0.91 for the Portland/Vancouver area.

$$\text{Field KWH/yr} = (1.2 * \text{DOE}) - 322 \text{KWH/yr}$$

$$r^2 = 0.91$$

With this, a Portland/Vancouver consumer can predict a refrigerator's yearly energy use from DOE test results.

3. Regressing average daily energy consumption per month with average monthly outside temperature gives an r^2 of 0.86. Other reports show ambient temperature regressed with energy use to approach r^2 values of .99 in controlled tests.^{4,5} Detailed kitchen temperature measurements would most likely have given higher r^2 values.
4. DOE tests predict actual annual energy usage more accurately than Japanese tests. ($r^2 = 0.91$ DOE vs. $r^2 = 0.85$ Japanese)
5. Peak monthly energy usage occurs in July and August and averaged 25% over average monthly energy use.
6. Peak weekly energy use is frequently in July or August but often results from an extraordinary usage, i.e. making ice sculptures, etc. Peak weeks average 59% over average weeks.
7. Average annual energy consumption averaged 16% below DOE predictions (25% below DOE predictions when not including refrigerators with anti-sweat switches.). This may be due to DOE running refrigerators with anti-sweat switches on 50% of the time compared to occupants who rarely adjust a refrigerator after installation.
8. Average annual energy consumption averaged 25% over Japanese predictions (15% over Japanese predictions when not including refrigerators with anti-sweat switches.).
9. Refrigerators with anti-sweat switches exceeded DOE predictions by 2 - 13%.
10. Regression of door counts with energy use gave very low r^2 values (averaging 0.10) with sufficient valid data.
11. Number of occupants and thermostat set points both showed very low correlations with energy use. Obtaining meaningful data for these particular correlations from such a small sample requires more detailed monitoring and/or better controls on variables.

It was interesting that many of the refrigerators exhibited an upward trend in energy use, though only of a couple percent. This may be due to occupants initially being self conscious about using a monitored refrigerator. Other factors could include changing of refrigerator adjustments, decreasing efficiency of compressor, etc. Further monitoring would be required to verify this trend or determine causes.

Results agree substantially with findings published in other studies. True kitchen ambient temperature measurements would probably provide much more accurate performance predictions. Energy use varies linearly with ambient temperature essentially independent of refrigerator door openings. Our derived equation uses both DOE predicted consumption and outside temperature for predicting performance of different refrigerators in varying climates.

Table 1 Energy Consumption Comparison

Site #	Brand	Model	Energy Use (KWH/yr)				% Difference	
			JPN	Field	Std Dev	DOE	JPN	DOE
531	Sanyo	457FBA	704	756	3	1049	7	-28
532	Sanyo	457FBA	704	678	10	1049	-4	-35
533	Hitachi	R-951SB*	986	1391	26	1365	41	2
534	Hitachi	R-951SB*	986	1425	60	1365	45	4
535	National	NR455ER-W	792	885	9	1077	12	-18
536	National	NR455ER-W	792	729	5	1077	-8	-32
537	National	NR434HV-W	449	549	2	675	22	-19
538	Mitsubishi	MR4236W	449	619	10	679	38	-9
539	Hitachi	R-942SID*	1142	2031	11	1799	78	13
540	Hitachi	R-316KV	292	413	4	537	41	-23
541	National	NR346HV-W	376	414	3	533	10	-22
542	National	NR306CG-W	365	421	8	573	15	-27
AVERAGE			670	859	13	982	25	-16

* Refrigerators with anti-sweat switches.

GRAPH 1 AGGREGATE ENERGY USE AND
OUTSIDE TEMPERATURE

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