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Japanese Refrigerators:
A Field Performance Analysis
Field Data Inspection, Screening, and Compilation

Prepared for
Bonneville Power Administration
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Lambert Engineering, Inc.

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Bonneville Power Administration Perspective

JAPANESE REFRIGERATORS: FIELD PERFORMANCE ANALYSIS DATA INSPECTION, SCREENING, and COMPILATION

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. This study showed that when tested to the DOE procedure, the 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

Overall, the data base was good. Missing data could be reconstructed in nearly all cases.

To check the validity of the data reconstruction, the annual energy consumption was calculated for each refrigerator. For most of the refrigerators, the calculated consumption fell between the DOE and Japanese laboratory estimates as anticipated. It was also close to preliminary calculations by BPA before all 18 months of data were collected.

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

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EXECUTIVE SUMMARY

Data has been collected on 12 Japanese-made refrigerators operating in the Portland-Vancouver metropolitan area. The data was gathered from data cards sent in weekly by participants over an 18 months period. The data is generally good. Some holes in the data exist but in nearly every instance the data was reconstructible.

The average annual energy consumption for each refrigerator was calculated. This value was computed by averaging the running sums of 52 weeks of continuous data for each refrigerator. The computed values were compared to laboratory results from both the U.S. Dept. of Energy and Japanese manufacturers.

Annual energy consumption typically rises as a function of the capacity (size) of the refrigerator. Two exceptions to this characteristic exist within the sample. The two Sanyo units exhibited significantly lower energy consumption for their size. Conversely, the only refrigerator with an ice maker consumed an unusually large amount of energy for its size. The presence of anti-sweat switches in three of the refrigerators may also increase energy consumption, although this has not yet been confirmed.

The field data generally falls within a range of values bounded by the Japanese and DOE lab results. However, several exceptions exist. Five of the field units had calculated values outside the laboratory ranges. Three of the units had values above the range (and also had anti-sweat switches). The other two units had values below the range.

The standard deviations of the average annual energy consumption values are generally good. Again, exceptions exist. While most standard deviations were within 1-1.5% of average values, two models (from the same manufacturer) had standard deviations of 2.4% and 4% of the average values.

A phenomenon associated with the standard deviations was observed. The 52-week running sums of energy consumption for nearly all refrigerators showed a gradual increase. Causes for this increase are unknown, but may be due to losses in efficiency due to aging. Further investigation is planned.

Three matched pairs of identical refrigerators were within the population. Even between matched pairs, annual energy consumption was highly variable. The pairs showed differences in the annual energy consumption ranging from 2.5% to 20%. Comparison of these six units to laboratory results show similar variability.

Overall, the data base is good -- missing values are generally reconstructible. Large variations in the calculated values for annual energy consumption will make further analysis difficult. Preliminary identification of significant differences between units has been made. Further analysis may help to explain the observed variations.

INTRODUCTION

Japanese refrigerators are generally regarded to be more energy efficient than their American-made counterparts. With increasing attention being focused on appliance energy efficiency, research into the operating characteristics of Japanese refrigerators has taken on new dimensions.

Other projects have reported the monitored energy use of certain models of Japanese refrigerators. (1,2) In addition, laboratory tests have been run to determine the energy consumption of certain refrigerators under controlled conditions. (3)

In 1987, the 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. (See Table 1) The purpose of this project was to collect field data on certain models and compare this data with data collected from other projects and from laboratory test results.

Twelve BPA employees were asked to place a Japanese refrigerator in their home and use it for 18 months. Sensors were installed on each refrigerator to measure the energy consumption in kilowatt-hours (kWh) and to measure the number of times the door was opened and closed (in counts). The twelve participants were asked to mail in completed monitoring cards on a weekly basis for 18 months.

The information on the card included: the site identification number, the meter reading for the electric meter measuring refrigerator energy consumption, the door counter number, the kitchen air temperature, and any comments the participant felt were pertinent to the project. The data from the cards were then input into a Lotus spreadsheet for analysis. A report of the preliminary analysis of the data was issued by BPA in March, 1989. (4)

Lambert Engineering received the Lotus data shortly after October 1, 1989 to proceed with a detailed analysis of the data. This report represents the first of four reports. It describes the methodology employed for inspecting, screening, editing, reconstructing, compiling and summarizing the data.

This report also presents preliminary results of the annual energy consumption of each of the 12 refrigerators. It compares these results to the results obtained in the BPA preliminary analysis, and to laboratory results from Japanese manufacturers and the U.S. Department of Energy. (3,4)

This report does not attempt to explain discrepancies between this analysis and other comparative studies. That task has been saved for a later report. The purpose of this first, preliminary report is to describe methodology and present preliminary results.

TABLE 1

DESCRIPTION OF THE REFRIGERATORS TESTED

SITE					No. of	Size
ID #	Brand	Model	Features (a)	Doors	c/f	(Liters)
540	Hitachi	R-316KV	TF	3	10.2	(289)
539	Hitachi	R-942SID	SS (ice sw)	2	14.8	(419)
533	Hitachi	R-951SB	SS (sw)	2	17.4	(492)
534	Hitachi	R-951SB	SS (sw)	2	17.4	(492)
538	Mitsubishi	MR4236W	TF	2	15.0	(424)
542	National	NR306CG-W	SS	4	10.7	(306)
541	National	NR346HV-W	TF	3	11.5	(325)
537	National	NR434TR-W	TF	2	14.9	(422)
536	National	NR455ER-W	SS	3	16.0	(453)
535	National	NR455ER-W	SS	3	16.0	(453)
531	Sanyo	457FBA	TF	2	19.6	(555)
532	Sanyo	457FBA	TF	2	19.6	(555)
	AVERAGE					

KEY: TF = TOP FREEZER
 SS = SIDE-BY SIDE
 ice = AUTOMATIC ICE MAKER
 sw = ANTI-SWEAT SWITCH

METHODOLOGY

Lambert Engineering, Inc. received the field data in a Lotus .WK1 computer file. The data was read into Lotus 1-2-3 (Version 3.0) for inspection. Overall, the integrity of the data is better than is common for a project of this nature.

The records were visually inspected for bad or missing data. In one instance, one month of duplicate records was deleted. Holes in the data were identified by reviewing the date stamp recorded for each card/week. In several instances, one week of data was missing. In a few instances, as much as several months was missing. Where it was apparent that a data card(s) was missing, a row(s) was inserted to represent the missing week(s). One row was inserted for each missing week.

After a row was inserted, the site identification (ID) number, month and day were typed in the appropriate columns. The month and day (but not the year) were added to the record as a check that the proper number of rows had been added, and that the dates were continuous on a weekly basis. The year was not typed in as an added identifier that the record was originally missing and had been added.

After date records were correctly set up, a column was added which served as a counter of weeks for each refrigerator. Week #1 was the first week of useable data on weekly energy consumption, usually the second week of data reporting. In one instance, useful data was not recorded until approximately the 12th week.

The next step in the analysis was to look at the energy consumption of each refrigerator. A column was added to compute the weekly energy consumption of each refrigerator. This was calculated by subtracting the meter reading of the previous week from the reading of the present week. Another column was added next to the calculated energy consumption column. This column was used to demark energy consumption values that had been reconstructed.

The computed weekly energy consumption data were inspected for bad or missing values. In a few instances, meter readings were erroneously inputted into the computer database. The errors were obvious and easily and unambiguously corrected. In a few instances the meter readings were discontinuous between adjacent weeks (i.e. the meter had been reset or changed out). Under these circumstances the weekly energy consumption value was erased for the week the meter reading was discontinuous.

In nearly all cases where data was missing, reconstruction of the data was possible. For example, eight weeks of data may be missing from the data set. The weekly average energy consumption around that time period might be 25 watt-hours (Wh). The difference in the meter readings spanning that eight week period would be

approximately 200 Wh (8 weeks x 25 Wh/week) in the data records. This procedure served as an indicator that the missing values were reconstructible.

Reconstruction of weekly values of energy consumption was performed. During the process of inspecting and reconstructing the data, the original data was never modified. Only values derived from the collected field data were reconstructed. This approach preserves the original integrity of the data and protects the analysis from erroneous user interference.

Where only one week of data was missing, two weeks had to be reconstructed (one representing the missing week, and one representing the week showing a "double" value). Usually in this instance, a simple average of the two-week total was calculated and inserted.

Where more than one week was missing, two different approaches were used. The preferred approach was to use an 8-week running average of the previous weeks' data to fill in missing blocks of data. For the last week, the value used equalled the difference between the total amount of energy consumed during the time period and the sum of the averaged missing values. This last step made sure that no mathematical errors were introduced into the reconstruction. Thus, the net energy consumption over the missing time period was left unchanged.

However this approach had a problem for relatively large blocks of missing data. After about four weeks the running averages were becoming averages of the data fills. This phenomenon usually led to a very large discrepancy at the end of the block.

To alleviate this problem, an alternative approach was developed. A weekly average of the energy consumption during the time period in question was calculated using meter readings at the beginning and end of the missing block of data, and the number of weeks missing. The average value was then inserted into all of the weeks except the last. The last week was treated the same as with the other approach described above. All reconstructed values were visually inspected for consistency with surrounding weekly values.

While this phase of the analysis did not use door counter information, some reconstruction of this data was performed. However, additional reconstruction is necessary. Reconstruction methods for this data, and other parameters, will be reported in a future report.

Reconstruction of weekly missing values had only minor impact on this analysis. The reason is that analysis of the energy consumption of the refrigerators on a weekly basis was outside the scope of this task. Instead, this analysis intended to calculate the annual energy consumption of each refrigerator for comparative analysis to other reports. The reconstruction process described

above was performed to build the foundation of a good data base upon which detailed analysis could be confidently executed.

Running sums were used to calculate the annual energy consumption of each refrigerator. The first sum represented the total energy consumption for weeks 1-52, the next for weeks 2-53, and so on, through the final week of data collection.

One requirement was placed on this approach of using running sums. The interval to be summed could not begin nor end on a week that had been reconstructed. The integrity of using reconstructed values in the annual sums was preserved so long as the entire missing block was included in the interval. However, using only part of a missing block would have introduced error since the weekly distribution of energy consumption during that time period could not be exactly known. Where an annual sum began or ended on a reconstructed week, the sum was erased and was not used in any additional analysis.

The annual energy consumption reported here for each refrigerator represents the average of the running annual sums available for each refrigerator. This approach biases the annual totals towards weeks in the middle of the data set. These weeks are included in each and every annual sum. Weeks at the beginning and end of the data collection period are added or deleted from the running sum.

The running sums for nearly all of the refrigerators began in July, 1987, and ended between October, 1988 and January 1989. This structure means the data between January, 1988 and July 1988 for all refrigerators is included in all of the running sums. This time period does not bound either the summer or the winter months completely. Therefore errors due to time-of-year biasing in the running sums should be negligible. Nevertheless, some biasing in the running sums may be present.

Despite this factor, this approach is statistically more valid than choosing just one annual sum. Similarly, using a procedure which discards values based on some pre-determined criteria was unacceptable. It was felt that 52 weeks of contiguous data was an important parameter in calculating the annual energy consumption. Throwing any value out would disrupt this continuity. In addition, it was unclear how to establish the criteria upon which to judge the weekly data.

For the averaged annual energy consumption calculated for each refrigerator, the standard deviation in the running sums was calculated. The standard deviation shows the relative spread in the running sum values. A low standard deviation indicates the running sums showed little variation over time whereas a large standard deviation indicates large variations.

RESULTS

Annual Energy Consumption Analysis

The average annual total energy consumption was calculated for each refrigerator. These totals are presented in Table 2. The standard deviation in the average annual total for each refrigerator is also given. The values obtained from an earlier analysis of this data are presented under the heading 'Lou'. (4) The annual energy consumption as measured in two different laboratory procedures is also included in the table. These laboratory results are from the U.S. Dept. of Energy (DOE) and from Japanese manufacturers (JPN).

As expected, the annual energy consumption of the refrigerators increased with size (capacity). Two exceptions to this trend are evident in Figure 1. First, the Hitachi Model R-942SID refrigerator (volume = 14.8 cubic feet) consumed a very large amount of energy for its size - three to four times the amount consumed by a National refrigerator of approximately the same size. The Hitachi unit was the only model in the sample with an ice maker. It also had an anti-sweat switch. Further analysis will focus on the possible relationship between these features and their impact on energy consumption.

The other notable exception in Figure 1 is the apparent high efficiency exhibited by both Sanyo units (volume = 19.6 cubic feet). These two refrigerators were a matched pair. In both instances this model showed a relatively low amount of energy consumption for its size.

Table 2 shows the relative difference between the field data and the other reports, as expressed as a percentage of the values presented in those reports. A negative number indicates the field data was less than the respective value it is being compared to.

The Japanese laboratory results are consistently much lower than their DOE counterparts. The field results generally lie within these two bounds. However, specific exceptions to this trend exist, and are noted below.

On the average, the 12 units were 25% higher than the average Japanese results, 16% lower than the average DOE results, and 2% higher than those calculated by Lou. However there is wide variation in these numbers between models, which dilutes the significance of these averages.

Specifically, of the 12 refrigerators, seven were inside the wide range delineated by JPN and DOE. These included one Hitachi, one Mitsubishi, four Nationals, and a Sanyo model. Of the five that fell outside this range, three were Hitachis, one was a National, and the other was a Sanyo.

TABLE 2

ENERGY CONSUMPTION COMPARISON FOR THE REFRIGERATORS TESTED

SITE ID #	Brand	Energy use (kWh/yr)					Diff %		
		JPN	Field	Std Dev	Lou	DOE	JPN	Lou	DOE
540	Hitachi	292	421	7	373	537	44	13	-22
539	Hitachi	1142	2012	50	1863	1799	76	8	12
533	Hitachi	986	1390	18	1337	1365	41	4	2
534	Hitachi	986	1426	61	1364	1365	45	5	4
538	Mitsubishi	449	617	9	617	679	37	0	-9
542	National	365	426	4	495	573	17	-14	-26
541	National	376	414	3	446	533	10	-7	-22
537	National	449	560	3	557	675	25	1	-17
536	National	792	740	2	698	1077	-7	6	-31
535	National	792	888	8	708	1077	12	25	-18
531	Sanyo	704	754	7	796	1049	7	-5	-28
532	Sanyo	704	678	10	751	1049	-4	-10	-35
	AVERAGE	670	861	15	834	982	25	2	-16

ANNUAL ENERGY CONSUMPTION FOR 12 JAPANESE REFRIGERATORS
FIGURE 1

All three Hitachi refrigerators had field values larger than the DOE lab results. All three units had anti-sweat switches. One of the units also had an automatic ice maker. The National and Sanyo units were below the JPN-DOE range.

The three Hitachi models with annual energy consumption values outside the JPN-DOE range had large standard deviations. This indicates the annual totals for these models are subject to wide variation. The cause(s) for the variations is unknown, and will be investigated and reported on in a later report.

The wide variation between the field data and other results, particularly the JPN and DOE laboratory results, is disturbing. The field data was collected under conditions entirely different than the laboratories, obviously. The large absolute differences between the field data and these lab results is not surprising. What is surprising, however, is the large relative variation between the field data and the lab results.

The field data is between -7% and 76% higher than the Japanese data, and between 12% and -35% lower than the DOE data. Further investigation and analysis may explain most of this variation.

A graph of the running sums indicates a general trend towards increased annual energy consumption for all but one or two of the refrigerators. Figures in the Appendix illustrate this phenomenon for each of the refrigerators. The rise may be due to a loss in energy efficiency due to aging. The explanation for this phenomenon is not within the scope of this report, but will be investigated further. Because the annual totals reported here are the average of these running sums, the apparent rise in the running sums increases the standard deviation associated with each average.

Matched Pair Analysis

Within the sample of 12 refrigerators are three matched pairs -- pairs of exactly the same model refrigerator operating in two different households. The pairs include a Hitachi, National and Sanyo model. Large differences are evident between two of these pairs. (See Figure 2.) Of the five refrigerators which were outside the JPN-DOE range discussed above, four of those units had a matched pair.

Table 3 shows a comparative breakdown of these units versus the DOE laboratory results. It is important to note that the DOE lab results are based on only two identical units and not a statistically large sample. The DOE laboratory results are within 6% of each other. The field results are within 20% of each other. The start and end dates for the running sums were approximately the same for each matched pair. Therefore differences arising from time-of-year biasing in the running sums will be negligible.

ANNUAL ENERGY CONSUMPTION FOR MATCHED PAIRS
FIGURE 2

TABLE 3

ENERGY CONSUMPTION COMPARISON OF DUPLICATE UNITS VS. DOE LAB RESULTS

BRAND	MODEL	FEATURES	SIZE CU.FT. (LITERS)	ENERGY USE (KWH/YR)					PERCENT ERROR
				DOE LAB TEST	FIELD TEST	UNIT #1	UNIT #2	UNIT #1	UNIT #2
				UNIT #1	UNIT #2	UNIT #1	UNIT #2	UNIT #1	UNIT #2
Hitachi	R-951SB	SS (sw)	17.4 (492)	1372	1357	1426	1390	4	2
National	NR455ER-W	SS	16.0 (453)	1106	1048	740	888	-33	-15
Sanyo	457FBA	TF	19.6 (555)	1040	1058	678	754	-35	-29

The field data for the two Hitachi units were within 2% of each other and yet still averaged over 3% over the laboratory results. The other two pairs showed considerably lower energy consumption when compared to the DOE results. Both the National and Sanyo pairs had one unit below the JPN-DOE range and one unit within the range.

Differences between the matched pairs may make correlation of the pairs to any general parameter difficult. Possible causes for the discrepancies include variations from manufacturer to manufacturer or unit to unit, product damage during shipment or differences in installation. In addition, differences between matched pairs could arise due to differences in ambient temperatures, number of door openings, refrigerator temperature settings, and family sizes. Analysis into the causes for the observed discrepancies is planned.

CONCLUSIONS

The data base for this monitoring project is generally good. Where holes in the data exist, reconstruction of the weekly energy consumption has been possible.

Preliminary analysis of the data indicates that annual energy consumption among the 12 refrigerators is highly variable. Annual energy consumption generally increases as the capacity (size) of the refrigerator increases. Two exceptions to this trend exist. The Hitachi Model R-942SID showed unusually large consumption for its size, probably because it was the only model in the sample with an ice maker. The two Sanyo units exhibited low energy consumption for their size.

The field results of the refrigerators generally fall within a range of values determined from laboratory results from Japanese manufacturers (on the low end) and the U.S. Dept. of Energy (on the high end).

Several exceptions to this observation exist. Of the 12 refrigerators, five of the units had an average annual energy consumption outside of the JAPAN-DOE range. All three units with anti-sweat switched were above the JPN-DOE range. Two refrigerators were below the range. Several factors may be responsible for the variability. They will be investigated and reported in a later report. The large variations, though, may make correlation of energy consumption to these factors difficult.

Within the sample were three matched pairs of identical refrigerators. Even between matched pairs, there was high variation in the calculated average annual energy consumption. The difference between pairs was calculated to be 2.5%, 11% and 20%.

The data is generally good, and the preliminary results exhibit trends. Large differences between field units and laboratory results, and between matched pairs, indicate that several factors may influence the annual energy consumption. Developing a prediction tool for annual energy consumption from the sample may be difficult.

Additional analysis is planned to attempt to explain discrepancies in the data reported here. Differences in model features and environmental and social factors have been identified and will be considered. Additional screening and compiling of the data is planned.

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APPENDIX

RUNNING SUM OF ANNUAL ENERGY CONSUMPTION
SANYO 457FBA (#531)

RUNNING SUM OF ANNUAL ENERGY CONSUMPTION
SANYO 457 FBA (#532)

RUNNING SUM OF ANNUAL ENERGY CONSUMPTION
 HITACHI R-951SB (#533)

RUNNING SUM OF ANNUAL ENERGY CONSUMPTION
 HITACHI R-951SB (#534)

RUNNING SUM OF ANNUAL ENERGY CONSUMPTION
NATIONAL NR455ER-W (#535)

RUNNING SUM OF ANNUAL ENERGY CONSUMPTION
NATIONAL NR455ER-W (#536)

RUNNING SUM OF ANNUAL ENERGY CONSUMPTION
NATIONAL NR434TR-W (#537)

RUNNING SUM OF ANNUAL ENERGY CONSUMPTION
MITSUBISHI MR4236W (#538)

RUNNING SUM OF ANNUAL ENERGY CONSUMPTION
HITACHI R942SID (#539)

RUNNING SUM OF ANNUAL ENERGY CONSUMPTION
HITACHI R316KV (#540)

RUNNING SUM OF ANNUAL ENERGY CONSUMPTION
NATIONAL NR346HV-W (#541)

RUNNING SUM OF ANNUAL ENERGY CONSUMPTION
NATIONAL NR306CG-W (#542)

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