EFFICIENT REFRIGERATORS IN JAPAN: A COMPARATIVE SURVEY OF AMERICAN AND JAPANESE TRENDS TOWARD ENERGY CONSERVING REFRIGERATORS

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ABSTRACT

Japanese refrigerators currently consume approximately half as much energy as American models, correcting for size differences, while retaining the frost-free feature. This enhanced level of energy conservation is the culmination of a more than ten year effort. This paper describes trends in Japanese refrigerator size, efficiency, and conservation technology, and compares and contrasts them to American data.

The size distribution is significantly different for Japanese refrigerators than for American models. The most popular Japanese size range is between 200 and 350 liters, whereas American refrigerators most commonly range from 400 to 600 liters. There are smaller differences in features offered. Frost-free top freezer models predominate in both markets.

Energy use for the Japanese refrigerators is typically about 300 to 350 kilowatt hours per year for a 250 to 300 liter unit vintage 1983-84; the comparable American figures are 1100 kilowatt hours per year and 475 liters.

Efficiency has improved markedly since 1972 for both American and Japanese refrigerators. However, the relative improvement for the Japanese models has been several times larger than for the American units. Comparisons of recent time trends in product efficiency offerings are provided.

Differences in test procedures between Japanese and American methods for determining energy consumption and refrigerated volume are presented. These differences introduce an element of uncertainty into international comparisons until uniform tests are performed. The magnitude of error is estimated to be up to 35%; however, current evidence suggests that the uncertainty does not reduce the magnitude of conservation achievement implied by the test results.

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I. INTRODUCTION AND SUMMARY

Japanese refrigerators currently use about half as much energy as American refrigerators while still retaining the self-defrosting feature. This reduction of energy use is due to the continuing application of advanced technologies for conservation, which are described in this paper. The trends in size, efficiency, and to some extent features, are significantly different in Japanese refrigerators compared to American ones, illustrating differences both in consumer preference and in manufacturers' success in improving the energy efficiency.

Typical Japanese refrigerators are in the size range of 7 to 12 cubic feet or 200 to 350 liters,1/ whereas typical American refrigerators range from less than 12 cubic feet to over 25 cubic feet, with the most popular size in the neighborhood of 17 cubic feet. A typical 230-330 liter (8-11 cubic foot) Japanese refrigerator with self-defrosting freezer uses less than 360 kWh/year; the most efficient model at the upper end in this size range uses only 300 kWh per year.2/ In contrast, a typical American self-defrosting refrigerator in the 16-17 cubic foot range uses 1100 kWh per year;3/ and the best American model uses about 900 kWh per year.4/ Thus, typical Japanese refrigerators use 45% less energy per unit volume than typical American ones. This relationship is the opposite of what one would expect based on the difference in size. In practice, for both American and Japanese refrigerators, energy consumption rises much more slowly than size. A formula the U.S. Department of Energy (DOE) used to characterize 1978 refrigerator sales implies that efficiency should decrease by 27% as size is decreased from 16 cubic feet to 9 cubic feet.5/ Yet the observed effect is an increase of over 80%.6/

This effect of size on the comparison of efficiencies can be reduced by comparing the largest size class of Japanese refrigerators with comparable American units. But this comparison is biased against the Japanese, who have concentrated on improving the efficiency of smaller models. The most efficient Japanese refrigerator of 15 ft^3 uses 456 kWh/year, while the most efficient 19.8 ft^3 model uses 696 kWh/year. In contrast, the most efficient self-defrosting American model in that size range (at 17.2 ft^3) consumes 875 kWh/year for a frost-free model, and even the best American partial automatic defrost model (14.2 ft^3 and 640 kWh/year) uses more energy per cubic foot than the best large Japanese self-defrosting refrigerators.

II. THE JAPANESE REFRIGERATOR MARKET

A. Size and Features

The average size of a Japanese refrigerator is currently about 230 liters.[7/] The size of Japanese refrigerators has been increasing, doubling since 1970.[8/] Industry sources project that average size will increase at a rate of 2 1/2% per year.[9/] Some 20% of refrigerator sales are very small units, under 100 liters. Another 20%, roughly, are from 100 liters to 170 liters. The 200 to 300 liter size class accounts for approximately 45% of the market. Refrigerators over 300 liters represent only 9% of the market, of which only 4% are larger than 400 liters.

The market is split among a very limited number of manufacturers. Three manufacturers, National, Toshiba, and Hitachi, share about 60% of the market almost equally. Other large manufacturers include Mitsubishi and Matsushita. The more luxurious models, from 200 liters and up, are almost all self-defrosting, and otherwise comparable in features and appearance to the more popular American models. The widest range of product offerings appears in the 230-325 liter size class. This class displays the most impressive results in terms of energy efficiency.

The self-defrosting feature was introduced in Japanese refrigerators around 1970. Since then, all of the major manufacturers but Toshiba have employed the American-style or "fan-method" of self defrosting. Refrigerators using this method isolate the evaporator or cold coil from the food compartment, and defrost the coil several times a day fully automatically. Toshiba employs a manually initiated self-defrosting system, which places the evaporator directly in the freezer compartment ("direct contact" cooling method) where it slowly builds up frost. When the frost becomes too thick, from one to three times a year, the user presses a defrost button and the freezer compartment defrosts itself and then resets and begins cooling again.

The Toshiba defrost system is different from the self-defrosting systems employed in American refrigerators. Toshiba argues that it is a preferable system, because it has several desirable features that balance the extra inconvenience of manually initiated self-defrosting. These features include two to three times more cooling capacity, the ability to stuff more food into a given volume of freezer space (because free air circulation is not necessary to transfer heat from the food into the cold coil), and about three to four decibels less noise. Also, the Toshiba system provides greater stability of temperature for stored food, since defrosting is accomplished only occasionally rather than several times a day. The first feature, increased cooling capacity, is particularly important because it is claimed to produce less damage to food being frozen, as well as being able to produce ice cubes more quickly. (Recently, other Japanese manufacturers have introduced the "quick freeze" feature into a small compartment of their freezers, and one American freezer includes this feature.)

The Toshiba method may be seen as either an amenity or disamenity by the American market. But the Japanese market perceives it as a comparable technology to the fan style automatic defrost models of Toshiba's competitors. This is demonstrated in the pricing levels of the different brands; Toshiba products lie in the middle or slightly below the middle of the price spread for each size class in which they compete, from 200 liters through 450 liters. This ranking is preserved also for the largest Toshiba refrigerators, which employ the fan style automatic defrost method. Toshiba holds a steady and slowly increasing market share. Thus, since its direct contact method freezers compete successfully with fan method automatic defrost freezers selling for comparable prices, the Japanese public evidently does not perceive a distinction in terms of amenity.

Other features typically offered in Japanese refrigerators include:

- A wide choice of colors, with manufacturers offering a selection of up to 8 colors in 1983;
- A 2-door refrigerator compartment, with one door opening onto a fresh vegetable storage bin;
- An extra-cold (-1°C) refrigerated compartment for storing fresh fish;
- A small door inside the main door to allow quick access to soft drinks, etc;
- Warning lights for incorrect temperature;
- Automatic icemakers on some models;

- Hinges that allow the door to open when the refrigerator is in contact with a side wall;
- Reduced noise;
- Reduced compressor size, for more interior volume.

B. Energy Consumption

The range of energy consumption available in Japanese refrigerators is indicated in Figures 1 and 2. As shown in Figure 1, the energy consumption of Japanese refrigerators is consistently lower than that of American frost-free refrigerators, and also lower than the energy consumption of American partials. Japanese refrigerators also exhibit the same trends of size vs. efficiency observed in American refrigerators: energy consumption increases much less rapidly than size.

Comparisons of energy efficiency between Japanese units can be made by adjusting for size with the DOE formula for energy factor as a function of volume.[10] Using this formula, the most efficient Japanese refrigerator is a 300 liter model that uses 300 kilowatt hours per year. It has equivalent performance to a 17 cubic foot refrigerator using 365 kWh/year.[11] This is a 45% reduction compared to the most ambitious DOE design studies in 1983,[12] or over 65% less energy than an average American frost-free unit.

In 1981, the most efficient large top freezer Japanese refrigerator was the Toshiba GR-411, at 14.5 ft^3. It used 540 kWh/hr. Since then, its performance has been surpassed by the National NR 433 TR at 15.0 ft^3 and 456 kWh/year. But this model uses 30% more energy than required by the most efficient 300 liter model, using the DOE formula to compare sizes. Similarly, the Sanyo SR 457 FB (19.8 ft^3 and 696 kWh/year) uses 80% more energy than would be projected by the DOE formula. Yet the Sanyo uses over 40% less energy than the most efficient comparably-sized American model.

Japanese refrigerators over 400 liters are rare, and are forecast to remain relatively uncommon in the future. Most of the Japanese side-freezer refrigerators are 400 liters in size or larger. Relatively less effort has been made to improve the energy efficiency of the Japanese side-by-side refrigerators. The overwhelming majority of these machines are in the 400-500 liter class. They range in energy consumption from 816 kilowatt hours per year to 1150 kWh/year. The upper end of this range is roughly comparable in energy performance to typical American side-by-side refrigerators; while the low end of the range is significantly better in performance than American models. Using

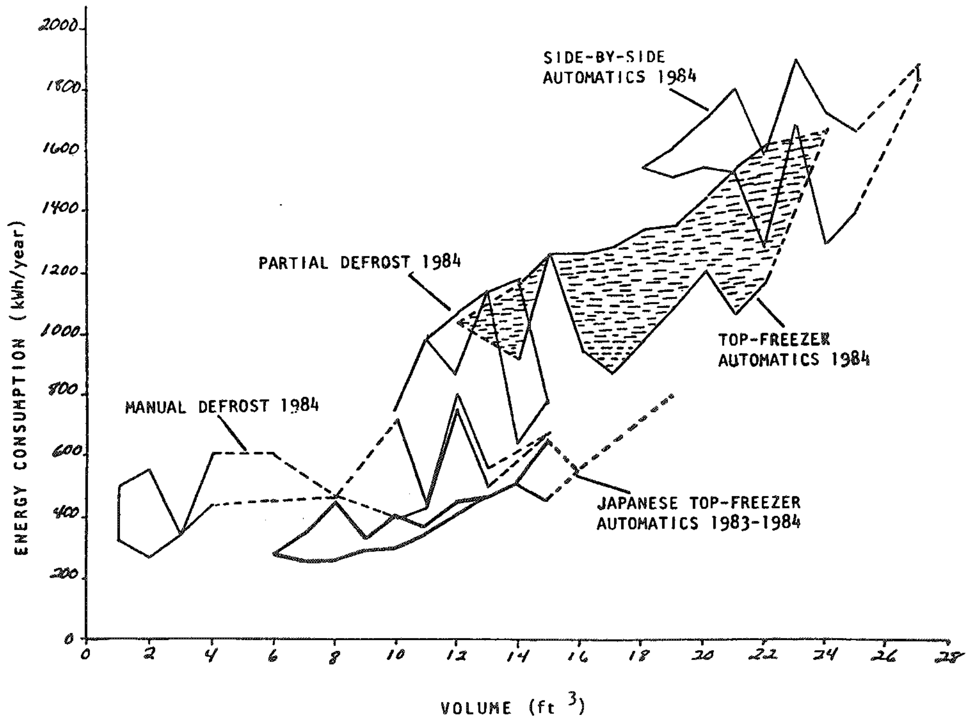

Figure 1: Energy Consumption vs. Volume for American & Japanese Refrigerators, 1983-84. Source: 1983-84 Japanese Manufacturers' Brochures and January 1984 AHAM Director

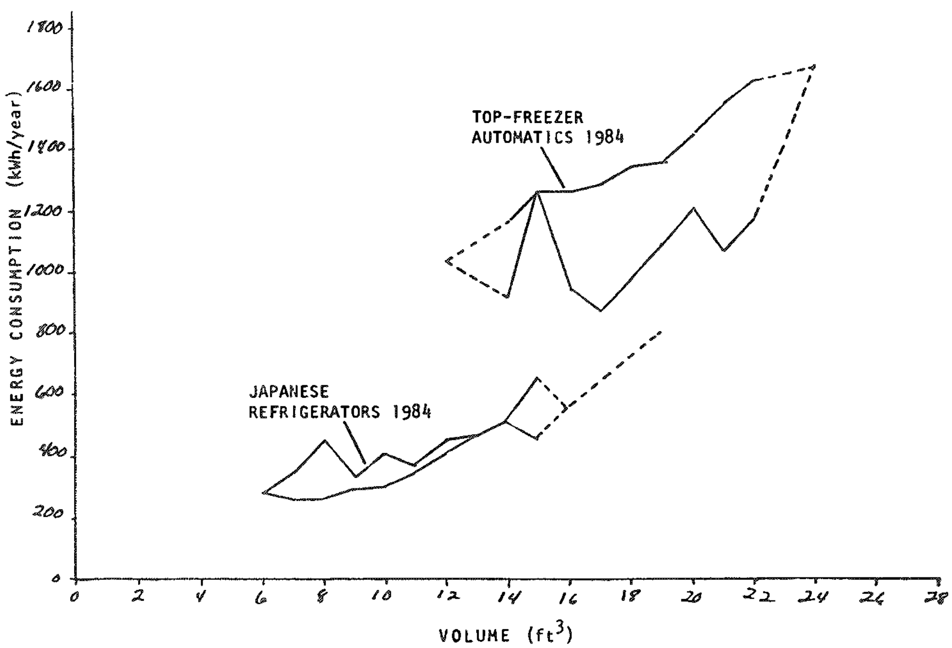

Figure 2: Energy Consumption vs. Volume, American & Japanese Top Freezer Automatic Defrost Refrigerators. Source: 1983-84 Japanese Manufacturers' Brochures and January 1984 AHAM Directory.

the DOE formula for side-freezer refrigerators[13/] to adjust for size, the most efficient Japanese side-by-side refrigerator (a Sanyo 343 TB at 421 liters (14.9 ft^3) and 816 kWh/year) uses the equivalent of 1060 kWh/year, compared with a 22 cubic foot model. The best American refrigerator in that size range uses 1288 kilowatt hours per year, or 20% more.

C. Improvements Since 1972

American refrigerators increased their efficiency by 59% from 1972 to 1981. This is equivalent to a reduction in energy consumption of 37%, holding size equal. For top-freezer frost-free models, energy use declined 42% holding size constant.[14/] The improvement in American refrigerators occurred by essentially one generation of major re-design. In 1974, a set of refrigerators was introduced that used approximately 35% less energy than an average 1972 refrigerator. This was equivalent to a reduction of well over 50% from the most energy consumptive refrigerator in each size class. This level of performance was matched by the entire market by 1981. But little additional progress was made from 1981 to early 1984: average efficiency increased by only 5% from 1981 to 1983.[15/]

The Japanese have made much larger and more continuous improvements in energy efficiency since 1972. For example, Toshiba has reduced its energy consumption per liter by 70% between 1971 and 1981. For Mitsubishi, the percentage reduction was 65%, for Hitachi 82%, and for National 79%. From 1981 to 1984, National reduced its energy consumption per liter another 40% compared to 1981 usage, while from 1981 to 1983, Mitsubishi and Hitachi reduced energy intensity by 35% and 18%, respectively. A small fraction of these improvements come naturally as a result of the continuing slow trend toward larger sizes. In recent years, energy efficiency for a given manufacturer has tended to improve by at least 10% compared to the previous year, controlling for size. Pre-1973 Japanese refrigerators appear to have been slightly more energy consumptive than their American counterparts, while current models have made much greater progress toward energy conservation.

The change in energy consumption offerings of Japanese manufacturers between 1981-2 and 1983-4 is illustrated in Figure 3. This figure shows the approximate range of variation in energy use of top-freezer self-defrosting refrigerators for each time period. The range is approximate because the surveys for each year are not exhaustive; however, they cover most of the market. As seen in the figure, there has been a marked reduction in energy use over the 2-3 year period throughout the range of sizes, in stark contrast to the U.S. manufacturers' offerings illustrated in Figures 4a & 4b. These figures show that the range of efficiencies available to the American consumer did not change substantially over these three years.

D. Japanese Technologies for Conservation

The efficient Japanese refrigerators generally employ technologies similar to those described in DOE or DOE-sponsored reports.[16/] The extent of application or effectiveness of these technologies is unknown, however, because the key parameters (*e.g.*, motor efficiency, EER, conductivity of insulation, etc.) are not quantified. Based on manufacturers' brochures and reference 7, the following techniques are commonly employed by Japanese manufacturers:

- More efficient compressor motors, with capacitor-run design and low-loss iron cores.
- Efficient rotary compressors
- Reductions in friction losses and fluid-flow resistance, and improvement of volume efficiency in the compressor
- Compressor waste heat vented to the air rather than transferred to the refrigerant
- Evaporator fan motor removed from the refrigerated volume
- Condenser tubing used for anti-sweat heaters
- Lower-conductivity foam insulation
- Independent temperature control of refrigerator and freezer compartments

III. TEST PROCEDURES

Energy consumption for refrigerators in normal use depends on a number of factors. These include ambient temperature and humidity, temperature settings inside the refrigerator, number and length of door openings, and the heat load imposed by food. Test procedures are intended to simulate simply the performance of a refrigerator subjected to typical conditions of use.

There are several ways this typical use pattern can be simulated. One method, used by the Association of Home Appliance Manufacturers (AHAM) and DOE, is to employ a simple

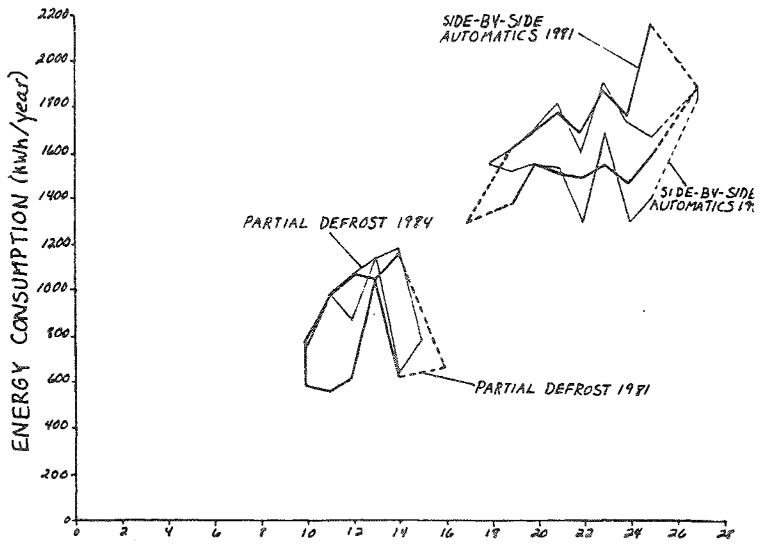

Figure 4a. Change in Energy Consumption for American Refrigerators Over Time

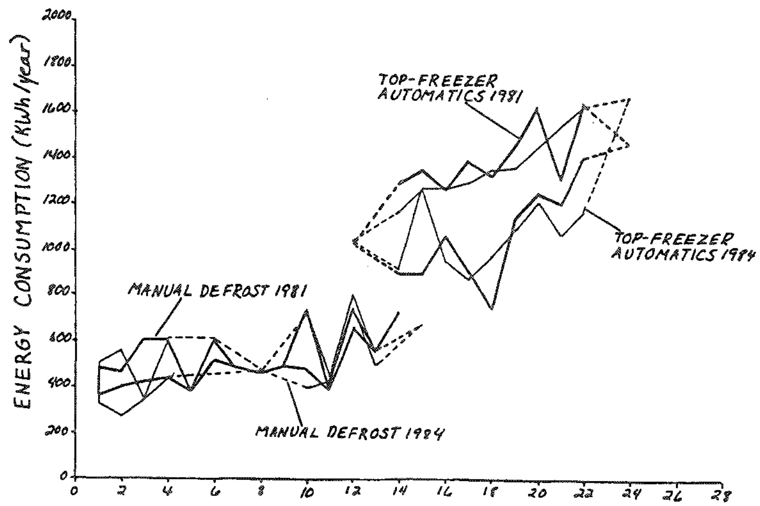

Figure 4b.

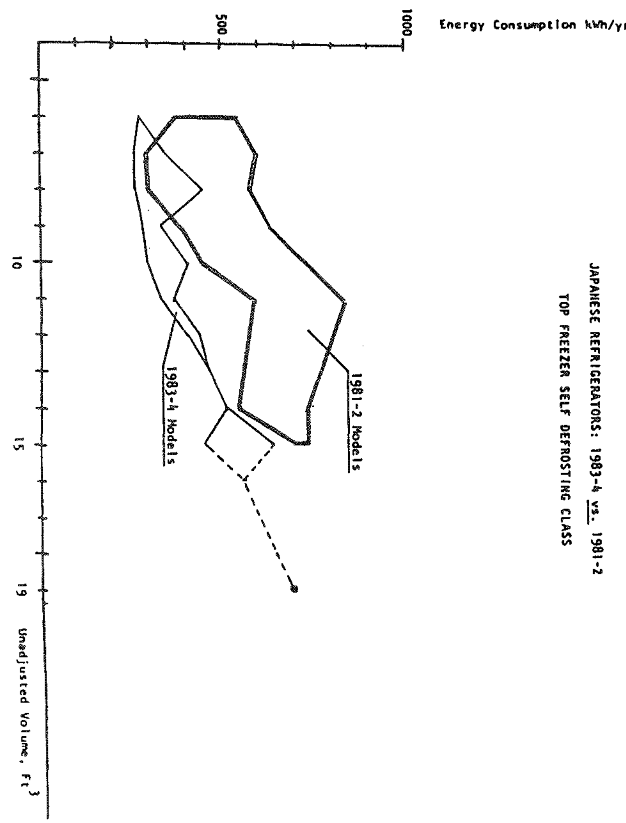

Figure 3: Change in Energy Consumption for Japanese Refrigerators Over Time

set of test conditions normalized to duplicate the results obtained in a field test. Another approach, used by the Japanese manufacturers and by some American researchers, is to simulate an average use cycle more closely and use the measured results without adjustment.

The AHAM test measures the energy consumption of a refrigerator in an environment with 90° F ambient air temperature. The doors are not opened in this test, and no food is introduced into the refrigerator. It is claimed to produce realistic estimates of energy consumption for 1975 vintage refrigerators.[17] There has been relatively little validation work concerning the procedure since that date, although the few tests that are available suggest that it remains approximately correct. But the test could become uncalibrated as the level of energy consumption changes from that originally used to validate the test procedure. This loss of calibration would occur because infiltration losses due to door openings and heat loads due to food, neither of which is measured in the AHAM test, are a larger fraction of the load of an energy-conserving refrigerator.

Two different tests of measured versus test-procedure results have been performed by Arthur D. Little, Inc. One study compared a cross section of 1975-style refrigerators, measured for energy consumption in the home, with their test procedure results, and also compared the most efficient Amana refrigerator under similar conditions for Miami and Orlando, Florida.[18] For Miami, the baseline units, representing a variety of units, used 20% more energy than the DOE test would predict. For Orlando, the comparable percentage was 21%. The number of data points was four for Miami and eight for Orlando. For the Amana units, the eight units in Miami used 22% more energy than the DOE test predicted, whereas the eight units in Orlando used exactly the amount of energy DOE predicted.

This study suggests at least rough agreement between the DOE tests and field results. We cannot generalize very far from this report, however, because of three primary problems. First, it refers to Florida, which has a distinctively warm climate compared with the rest of the United States. Energy consumption of a refrigerator is larger in warm climates; so one cannot be sure whether the over-consumption of energy measured in this test is due to climatic effects or problems with the test procedure. Second, the number of data points is small, and no information is provided concerning the representativeness of the families whose energy consumption was measured. Finally, the report does not specify the duration of the period over which the data were collected. Since energy consumption varies significantly by seasons, measuring for less than a year could bias the results.

The second ADL survey compared conventionally designed refrigerators with a prototype ADL/Amana model.[19] The test site was Norfolk, Virginia. Over the course of the test year, the conventional refrigerator used 29% more energy than the DOE test procedure, while the energy-efficient prototypes used exactly the same amount of energy as predicted by the DOE test.

The absolute levels of energy use found in this survey have limited generality as well, primarily because of the non-random nature of its sample of metered houses, and the fact that they were all in one locality. The non-random sample is a potential problem because of the wide variability between households, while the use of a single climate is troublesome because of the seasonal variations in energy consumption measured in the study. However, the relative comparison between the efficient units' energy use and the base-case units' consumption appears more general in applicability, because the problems noted above do not affect the calculation of energy savings to first order.

The Japanese test procedure, compared with its American counterpart, is more difficult to perform, but involves reasonable ambient temperatures and includes door openings.[20] The ambient temperatures are typical of those encountered in Japan; they are slightly cooler than typical for the United States. Energy consumption is measured for one day at 15°C(59°F) and for one day at 30°C (86°F). Ambient humidity is set at 75%. The 30° results are weighted by 100 days per year, while the 15° results are weighted by 265 days per year. Thus, the weighted average temperature is 66°F.

In contrast, interior temperatures are set at lower levels in the Japanese test compared to the American. The freezer unit is tested at -18°C or 0°F while the refrigerator is tested at 3°C or 37°F. The American test procedure sets the freezer temperature at 5°F. During the course of the Japanese test the door is opened 15 times a day for the freezer, once every 40 minutes, and 50 times per day for the refrigerator, once every 12 minutes. The doors are opened for 10 seconds to an opening angle of 90°.

The Japanese test procedure is claimed to be a reasonably accurate predictor of energy consumption in the home, with more likelihood of over-predicting energy use than under-predicting.[21]

There has been little systematic comparison of energy consumption measured by the U.S. test relative to the Japanese test. One test of a single unit described by William Beard of Whirlpool Corporation measured the energy use of a National

NR433TR, which is rated by the Japanese test at 456 kWh/yr. The measured energy use on the U.S. test was 603 kWh/yr., 32% higher than the Japanese rating.22/ However, Beard has suggested that a 20% difference between the results of the different test procedures may be more typical.

There are several hypotheses that can explain this result. The test may simply reflect one anomalous unit; however, a 32% variation between individual units seems unlikely. A second hypothesis is that the Japanese test understates actual energy consumption. A third hypothesis is that the Japanese method accurately predicts real-world energy consumption while the U.S. method over-predicts actual usage for energy-efficient designs. Alternately, some combination of the second and third hypotheses suggests that real-world energy consumption may fall between the results of the American and Japanese tests.

Regardless of which of these hypotheses is true, the data presented above are not consistent with the explanation that Japanese refrigerators do not save as much energy compared to American models as the tests predict. The ADL studies show that the DOE test understates the difference between the energy efficient refrigerators measured and the conventional ones. Based on these tests, one must conclude that either the DOE test correctly predicts the performance of the efficient units and underpredicts the conventional models, or the more likely case that the DOE test overpredicts energy use for the efficient models and correctly predicts the conventional ones. In either case, the difference between the two refrigerators -- the conservation potential -- is underpredicted by the DOE test.23/ Thus comparing the DOE-test measurement of a Japanese refrigerator to the DOE-test measurements of American refrigerators most likely understates the amount of energy saved by the Japanese unit.

While comparisons of the relative energy use of Japanese and American refrigerators can be made with relatively little uncertainty despite questions about test procedures, it is much more difficult to pin down absolute energy use. These questions cannot be resolved without further testing of Japanese and American products, using both test methods and comparing to in situ data.

The Japanese test procedure for volume computes the net interior volume excluding the space occupied by the lamp, the tray and shelf supports, all boxes, panels, baffles, etc. and all non-removeable shelves, etc.24/ The space occupied by easily removable parts, such as crisper and meat keeper, is included in the refrigerated volume.

This test appears comparable in definition and intent to the U.S. test. A spot check performed by Mr. Beard in conjunction with the energy tests described above produced equivalent results from both test methods. On the other hand, a test described by Whirlpool found that a Toshiba GR-411 rated at 14.5 ft^3 had only 12.5 ft^3 of volume measured by the U.S. test.[25] This test, whose results conflict with both the Beard test (performed by the same corporation) and the clear wording of the procedures, may be incorrect. Further measurements are needed to establish conclusively the relationship between U.S. and Japanese volume test methods.

V. CONCLUSION

Japanese refrigerators marketed in 1984 appear to demonstrate the feasibility of reductions in energy use of one-half or more compared to current American practice. Uncertainties in the comparison of efficiency as a function of volume and in evaluating the accuracy of energy-use test procedures casts doubt on the exact magnitude of savings achieved by current Japanese units, but even the most pessimistic conclusion consistent with the data is that Japanese refrigerators use 50% less energy than their American counterparts.[26] The history of large relative improvements in the Japanese refrigerators, which is nearly independent of concerns about the accuracy of the test procedure, corroborates the conservation savings estimates: if Japanese refrigerators actually used more than 50% of the energy than American models in 1984, that would imply an unrealistically high consumption compared to American models in the early 1970's.[27]

The level of conservation achieved by the Japanese refrigerators, assuming the Japanese test procedures are accurate, is consistent with calculations of cost-effective conservation measures for American refrigerators. Both the Japanese experience and studies on American refrigerators[28] lead the analyst to the conclusion that a cost-effective level of energy consumption for a 500 l or 17 ft^3 automatic-defrost refrigerator is about 400 kWh/yr or less.

FOOTNOTES

1/ These sizes are the measurements resulting from using the Japanese test procedure. This procedure appears to be comparable to that of AHAM and DOE. See Section III.

2/ All numbers for energy consumption reported in this paper are based on the Japanese test procedure as reported by the manufacturer. See section III.

3/ This is the middle of the range of energy use found in the January 1984 AHAM Directory (Association of Home Appliance Manufacturers, Chicago, Ill.).

4/ Ibid.

5/ The DOE correlation establishes that Energy Factor varies with unadjusted volume V according to the formula EF = 1.69 x 0.178 x V. As V is changed from 16 ft^3 to 9, EF varies from 4.538 to 3.297, a reduction of 27.5%. See Federal Register 45, 127, pp. 43985-6, 30 June 1980.

6/ Efficiency is inversely proportional to energy use, holding size constant, so a 45% reduction in energy use is equivalent to an increase in efficiency to 1/(1-.45) or an increase of 82%.

7/ Haruki Tsuchiya, "Energy Efficiency of Refrigerators in Japan." Research Institute for Systems Technologies, Tokyo, 1982.

8/ Ibid.

9/ Toshiba Products Guide, 1982.

10/ Energy factor is the inverse of energy consumption per day divided by adjusted volume in cubic feet. Energy factors are not relevant to the discussion of the text; however, they can be interpreted as relative rankings of the efficiency. As noted, the DOE formula for energy factor for existing top-freezer refrigerators is EF = 1.69 + 0.178 V (see note 5). This empirically derived formula can be used to adjust efficiency with volume.

11/ The DOE formula predicts an increase in energy factor of 37% from 300 liters to 17 ft^3, or a consumption decrease of 24%. Scaling the 300 kWh/year for 300 liters up to 17 ft^3 and then reducing the result by 24% leads to a projected electricity consumption of 365 kWh/year.

12/ "Supplement to: March 1982 Consumer Products Efficiency Standards Engineering Analysis and Economic Analysis Documents" (U.S. Department of Energy, DOE/CE-0045, July 1983). The most efficient top-freezer frost-free design of 17 ft^3 uses 672 kWh/yr. (p. D1-11).

13/ The DOE formula for energy factor as a function of volume for side-freezer refrigerators is EF = 3.19 + 0.09 V. See note 5.

14/ "1983 Energy Consumption and Efficiency Data for Refrigerators, Refrigerator-Freezers, and Freezers," Association of Home Appliance Manufacturers, Chicago, Ill., 1984.

15/ Ibid.

16/ See "Study of Energy-Saving Options for Refrigerators & Water Heaters, Volume 1: Refrigerators" A.D. Little, Inc., for Federal Energy Administration; May 1977. "Development of a High Efficiency, Automatic Defrosting Refrigerator/Freezer, Phase I-Design & Development. Final Report, Volume II, R&D Task Reports," Arthur D. Little, Inc., for Oak Ridge National Laboratory, ORNL/Sub-7255/2, 1980; Consumer Products Efficiency Standards Engineering Analysis Document, U.S. DOE, DOE/CE-0030, 1982; and reference 12.

17/ See Berman, et al., "Electricity Consumption in California: Data Collection and Analysis," Lawrence Berkeley Laboratory, UCID-3847, 1976. Available from the California Energy Commission.

18/ W. Thompson Lawrence, "Field Test Measurements of Energy Savings from High Efficiency, Residential Electrical Appliances. Arthur D. Little, Inc., Cambridge, Massachusetts 02140. Presented at the ACEEE Summer Study, Santa Cruz, California, August 1982.

19/ See R.F. Topping, "Development of a High Efficiency Automatic Defrosting Refrigerator-Freezer, Phase 2, Field Test," Vol III, Oak Ridge National Laboratory, ORNL/Sub/77-7255/3, 1982.

20/ Japanese Industrial Standard, JIS C 9607, 1979, Appendix 3 translated and published by Japanese Standards Association.

21/ Personal communication, Haruki Tsuchiya, April 1981.

22/ See "Technical Analysis of the Energy Conservation Potential for Refrigerators, Refrigerator-Freezers, and Freezers," Part I, M. Messenger and R.M. Martin; California Energy Commission staff draft, May 1984.

23/ For example, if we assume the DOE test is correct for efficient units and underpredicts energy use for conventional ones by ADL's 29%, then the field usage of the National refrigerator is equal to Beard's DOE-test measurement of 603 kWh/year while the field usage of the typical American unit of comparable size is 1419 kWh/yr, or 29% higher than the DOE test. The Japanese model then uses 42% of the energy of the typical American model. Alternately, if we assume that the DOE test overpredicts the actual energy use of the Japanese model, its field energy use is most reasonably expected to be given by the results of the Japanese test, or 456 kWh/yr. The field energy use of the conventional American unit is in this case given correctly by the DOE test of 1100 kWh/yr. Thus, the

Japanese model uses 41% of the energy of the American unit, which is virtually no different than the previous case.

24/ See reference 20, Appendix 1.

25/ See transcript, California Energy Commission business meeting, January 11, 1984.

26/ This conclusion is based on the assumption that the efficiences of the less intensively redesigned 15-20 ft^3 Japanese refrigerator should be compared to those of American units in the same size range (or alternatively that energy use per liter should be compared directly without correcting for size). As discussed in note 23 above, it is almost independent of the comparison of DOE test and Japanese test results.

27/ Since the minimum decrease from 1972 to 1983-84 recorded by any Japanese manufacturer was 77.3%, the energy consumption in 1972 of a unit currently using, say, 70% of present American energy consumption would have been 3.1 times 1984 usage, or 1.8 times 1972 American energy use.

28/ See D.B. Goldstein, "Efficient Refrigerators: Market Availability & Potential Savings," in What Works, ACEEE, Washington, D.C., 1984, and D.B. Goldstein, "Advanced Technology Options for Refrigerator Design Engineering Analysis," Appendix B, ref. 22.