

Actual Energy Consumption of Top-Runner Refrigerators in Japan

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Abstract

In Japan, energy efficiency standards for domestic refrigerators were established in 1999 in accordance with the guidelines delineated by the Top-Runner program. The goal was an improvement in energy efficiency of approximately 30% compared with the year 1998 by the year 2004. This goal has been not only met but exceeded: the average annual electricity consumption of products shipped in 2004 was 290 kWh/year, a 55% reduction of the 1998 figure.

Electricity consumption of refrigerators is measured using the Japan Industrial Standards (JIS) test procedures. However, existing surveys show significant difference in electricity consumption between the actual and the labeled.

This paper analyzes the difference between actual values and labeled values of electricity consumption. Actual values were obtained by conducting two experiments. The first experiment measured electricity consumption of two high efficient refrigerators in a laboratory simulating actual use conditions. The refrigerators were found to consume two to three times more electricity than under JIS test conditions. The second experiment monitored over 100 refrigerators in households. According to the first year's result, the average annual electricity consumption was 65% larger than the JIS test value.

Energy efficiency of refrigerator has been improved, but the significant difference in electricity consumption between the actual and the labeled might damage the public trust in labeling. The government began studying new standard and test procedure of refrigerators in September 2005. The JIS test procedures were revised to be much similar to real usage in January 2006 and the standards will be established by the end of the year.

Introduction

In 1998, the Japanese government started to revise energy efficiency standards for machinery and equipments by using the Top-Runner approach which was how to establish standards based on the efficiency of the most efficient product at the time^[1].

The standards were set in 1999 for domestic refrigerators and freezers which accounted for approximately 17% of electricity consumption in the residential sector. The target year of the standards was 2004.

The annual electricity consumption standard is defined as a function of adjusted rated volume for each category (see **Table 1**). The most popular type of refrigerator-freezer is Category VI. A typical Category VI refrigerator-freezer has 300 liters of fresh-food storage capacity and 100 liters of three-star freezer capacity. As its adjusted rated volume is 515 (=300 + 100 x 2.15) liters, the standard electricity consumption value is 408 kWh/year.

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Manufacturers are required to label their products with an annual electricity consumption value that is measured by JIS test procedures. In each manufacturer and category, the average electricity consumption weighted by shipment may not exceed the standard value. In case the weighted average remarkably exceeds the standard value, the Minister of Ministry of Economy, Trade and Industry recommends manufacturers to improve the annual electricity consumption. If they do not follow the recommendation, the Minister announces to the public and may order the manufacturer to follow recommendations.

Table 1. Energy efficiency standards for refrigerators and freezers

Category		Target standard value
Refrigerator	I refrigerator (natural convection)	$E \text{ (kWh/year)} = 0.427 \times V_{adj} \text{ (L)} + 178$
	II refrigerator (forced circulation)	
Freezer	III freezer (natural convection)	$E \text{ (kWh/year)} = 0.281 \times V_{adj} \text{ (L)} + 353$
	IV freezer (forced circulation)	
Refrigerator-freezer	V refrigerator-freezer (natural convection)	$E \text{ (kWh/year)} = 0.433 \times V_{adj} \text{ (L)} + 320$
	VI refrigerator-freezer (forced circulation, with a specific technology)	$E \text{ (kWh/year)} = 0.507 \times V_{adj} \text{ (L)} + 147$
	VII refrigerator-freezer (forced circulation, without a specific technology)	$E \text{ (kWh/year)} = 0.433 \times V_{adj} \text{ (L)} + 340$

Source: [2]

Note 1: Specific technologies refer to inverter technology and vacuum insulation. An appliance that incorporates either or both of these technologies is categorized as VI.

Note 2: V_{adj} : Adjusted rated volume

JIS test procedures of refrigerators were made in 1979 and revised twice. The revision in 1993 was carried out in order to follow the international standard, but the procedures were revised again to resemble actual use conditions when the standards were set. In this paper three testing methods, Method A, B and C are described. (See **Table 2**).

Table 2. Changes in JIS test procedures of refrigerators over time

Testing method		A	B	C	
Name of standard		JIS C9607	JIS C9607	JIS C9801	
Year		1979	1993	1999	
Type				Forced circulation	Natural convection
Ambient temperature		30°C : 100days 15°C : 265days	25°C	25°C	
Relative humidity		75%±5%	45% - 85%	70%±5%	
Installation	back	On the wall			
	sides	300mm away from walls			
Load	fresh food	No	No	No	No
	freezer	No	Yes	No	Yes
Storage temperature	fresh food	3°C±0.5°C	≤ 5°C	≤ 5°C	
	freezer(***)	-18°C±0.5°C	≤ -18°C	≤ -18°C	
Open/close door	fresh food	50 times	no	25 times	
	freezer	15 times	no	8 times	

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Since 1999, labeled annual electricity consumption of refrigerator-freezers by testing Method C has been rapidly reduced (See **Table 3**). In particular, the improvement from 1999 to 2004 was more than 60% in appliances belonging to the 400+ liters category. The labeled value of the Top-Runner product in 2004 achieved energy efficiency as low as 150 kWh/year.

Due to such improvements, the weighted average annual electricity consumption of shipped refrigerator-freezers and refrigerators in 2004 was 290 kWh/year, a reduction of 55% from the base year and substantially below the target. Freezers also met the requirement easily (see **Table 4**).

Table 3. Labeled annual electricity consumption of refrigerator-freezers

Year	141L - 200L				351L - 400L				401L - 450L				451L - 500L			
	min.	avg.	max.	#	min.	avg.	max.	#	min.	avg.	max.	#	min.	avg.	max.	#
1999	490	577	640	7	470	630	830	26	450	619	980	21	460	725	1030	17
2000	500	572	630	5	380	556	760	18	370	447	710	18	380	584	1030	22
2001	420	533	630	4	340	464	690	19	330	404	710	16	340	466	960	15
2002	390	475	630	8	300	432	690	18	280	342	440	18	280	412	960	19
2003	370	442	580	6	190	372	690	17	200	318	440	25	200	336	690	16
2004	350	376	420	7	180	299	390	15	150	236	440	22	180	253	370	15
'04/'99	71%	65%	66%		38%	47%	47%		33%	38%	45%		39%	35%	36%	

Source: Energy Conservation Center, Japan [5]

Note: unit* kWh/year

Table 4. Energy efficiency improvement of refrigerators and freezers

Type	Year		Weighted average electricity consumption of shipped products	Improvement rate
Refrigerator and Refrigerator-freezer	1998	Actual	647.3 kWh/year	Base year
	2004	Target	449.7 kWh/year	30.5%
		Actual	290.3 kWh/year	55.2%
Freezer	1998	Actual	524.8 kWh/year	Base year
	2004	Target	404.7 kWh/year	22.9%
		Actual	369.7 kWh/year	29.6%

Source: [3]

However actual electricity consumption does not seem to have been rapidly reduced during this period. Three laboratory tests conducted between 2001 and 2004 by Japan Consumer's Association (JCA) and National Consumer Affairs Center of Japan (NCAC) show considerable difference between actual and tested electricity consumption (see **Figure 1**). In particular, existing survey A shows that actual values were twice or more than three times as large as labeled values.

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Each test condition was similar to JIS test conditions with the exception of installation place and load. Products tested by JCA [5][7] were installed 5 millimeters away from both side walls while products tested by JIS were installed 300 millimeters away. Also, both the JCA test and the NCAC test placed load in the form of items to be cooled/frozen into the fresh food and freezer compartments before testing, while the JIS test did not do so for appliances with forced circulation. Additionally, the NCAC test [6] varies the load during the test period.

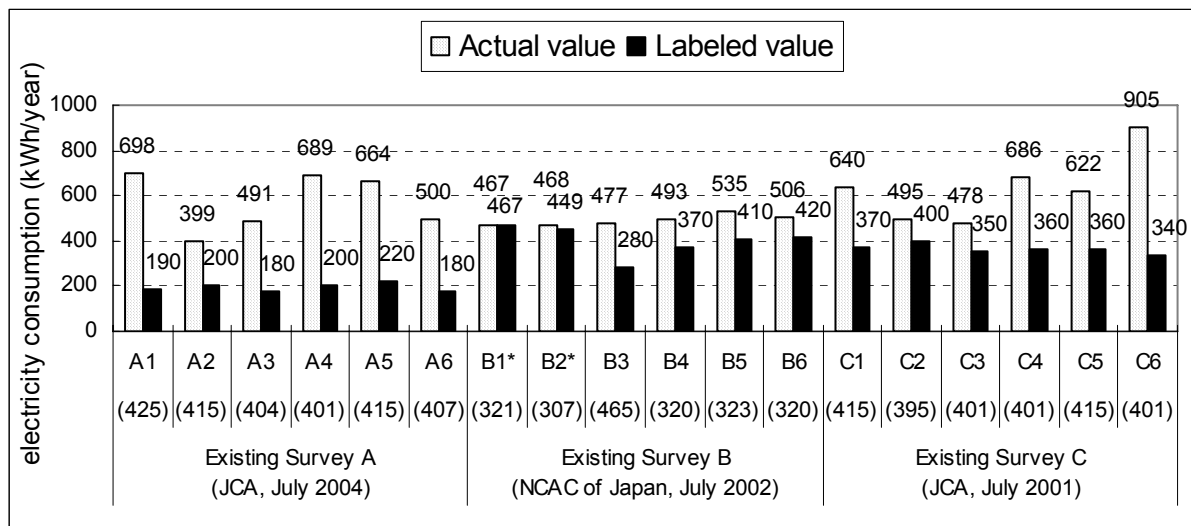


Figure 1. Examples of comparison of actual versus labeled electricity consumption of refrigerator-freezers

Source: [5], [6] and [7]

Note1: B1 and B2 are natural convection types made by European manufacturers. The others are forced circulation types made by Japanese manufacturers.

Note2: Value in parentheses refers to the rated volume.

Laboratory test

Jyukankyo Research Institute (JYURI) tested the electricity consumption of two Top-Runner refrigerator-freezers in 2004 (see **Table 5**). The test was conducted as part of survey on how users' actions could influence energy consumption [9]. JYURI was entrusted with the testing and evaluation by Energy Conservation Center, Japan (ECCJ).

Test conditions are shown in **Table 6**. They are based on the JIS test conditions, with the exception of ambient temperature and relative humidity, which were set to simulate actual use conditions. The purpose of the test is to figure out the effect of user's actions, such as appropriate installation, mild temperature setting, refrainment from stuffing, etc.

Japan Electrical Safety and Environment Technology Laboratories (JET) provided a temperature and humidity controlled laboratory. The testing procedure is as follows:

1. All storage compartments, water tank, and ice box shall be empty. Automatic ice making function is off. Every switch that can be turned off is off.

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2. Storage compartments' temperature is set to "middle". Twelve hours (twenty four hours for the first time of testing) after appliances are turned on, defrosting and monitoring commence simultaneously.
3. Three hours after monitoring begins, the door of the fresh food compartment is opened and closed 25 times every 12 minutes and the door of the freezer compartment is opened and closed 8 times every 40 minutes. (This step is the same as the JIS testing procedure.)
4. Monitoring is complete after 36 hours.

Table 5. Tested products

Product	Type	Volume	Number of doors	Category	Labeled electricity consumption
Refrigerator-freezer A	Forced circulation	401L	5	VI	200 kWh/year
Refrigerator-freezer B	Forced circulation	404L	5	VI	180 kWh/year

Table 6. Test conditions

Feature		JYURI Test	JIS C9801 (Forced circulation)
Ambient temperature		22°C	25°C
Relative humidity		60%±10%	70%±5%
Installation	back	On the wall	On the wall
	sides	5mm away from wall (one side only)	300mm away from walls
Load	fresh food	No	No
	freezer	No	No
Storage temperature	fresh food	Middle	≤ 5°C
	freezer	Middle	≤ -18°C (***)
Open/close door	fresh food	25 times	25 times
	freezer	8 times	8 times
Defrosting		Monitoring and defrosting begin simultaneously.	Monitoring begins after defrosting.
Automatic ice making		Off	Off

The results are shown in **Table 7**. Annual electricity consumption was more than twice or three times as much as the labeled value. This was similar to the results of existing surveys. Although storage compartment temperature does not follow the JIS testing procedure, there is no significant difference.

Table 7. Results of JYURI test

Product	Annual electricity consumption	Comparison with the labeled value	Storage temperature	
			fresh food	freezer
Refrigerator-freezer A	604.8 kWh/year	+202%	4.9°C	-19.2°C
Refrigerator-freezer B	423.8 kWh/year	+135%	3.8°C	-17.2°C

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The manufacturers of Refrigerator-freezer A and Refrigerator-freezer B analyzed the factors for the significant difference in actual versus labeled electricity consumption. The findings regarding Refrigerator-freezer B were reported in September 2005^[3]. According to the report, the main reason for the discrepancy was the operation of heaters under actual conditions, which caused an increase in cooling load and led to increased electricity consumption (see **Table 8**).

The difference can be attributed to the embedded control program which minimizes the operation of heaters under a stable condition (ambient temperature: 25°C, fresh food compartment: 5°C, freezer: -18°C). In order to hinder such schemes, the testing procedures are required to be more complicated and to contain several conditions.

Table 8. Contributing factors to the difference in electricity consumption between actual and labeled (Refrigerator-freezer B)

Factor	Contribution
Installation (distance from wall)	+24%
Ambient temperature	-13%
Operation of temperature compensating heaters	+21%
Operation of heaters for the prevention of ice formation on pipes	+29%
Operation of heaters for defrosting	+7%
Increase of cooling load by frequent heater operation	+39%
Other (individual difference, unknown)	+28%
Total	+135%

Source: [3]

End-use monitoring

In July 2004, JYURI started a large end-use monitoring survey on electricity demand. The survey was entrusted by Central Research Institute of Electric Power Industry (CRIEPI) and was funded by Ministry of Economy, Trade and Industry (METI).

Major appliances, including refrigerators and freezers, in ninety-six households were monitored. In these households, room temperature was also measured (see **Table 9**). One hundred five refrigerators or freezers, accounting for 97% of all units owned by monitored households, were monitored (see **Table 10**).

Monitoring interval is 30 minutes. Each meter sends its data to a parent meter installed on a power distribution board through a power line carrier (PLC). Data in parent meters are remotely accessed through a public line.

Table 9. Number of monitored households

Area	Number of households
Metropolitan Area	31
Osaka-Kobe Area	65
Total	96

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Table 10. Monitored units

Item	Number of units (total)	Number of monitored units	Percentage of monitored units
Air conditioner	256	192	75%
Refrigerator and freezer	108	105	97%
TV set	192	162	84%
Personal Computer	180	34	19%
Other (heater, etc)	—	70	—
Total (Appliance)	—	563	—
Room temperature	—	171	—

Annual electricity use in monitored households is 4,631 kWh/year on average, excluding use by metering equipment. Refrigerators and freezers consume 18% of the total, making them the largest consumers of electricity of all appliances (lighting equipment excluded) (see **Figure 2**). Daily electricity use by refrigerators and freezers varies seasonally, from 1.6 kWh/day to 3.0 kWh/day (see **Figure 3**).

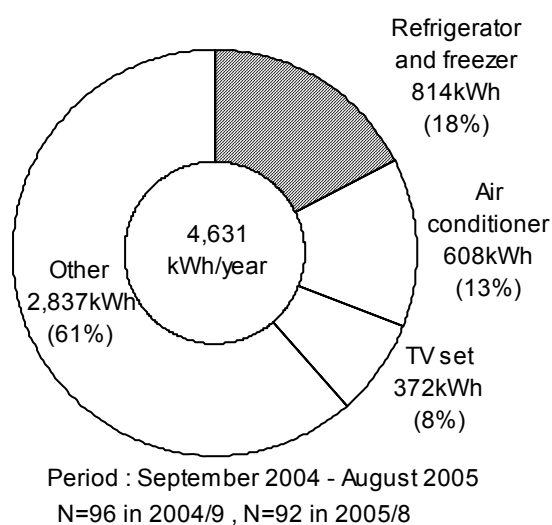


Figure 2. Annual electricity consumption in monitored households

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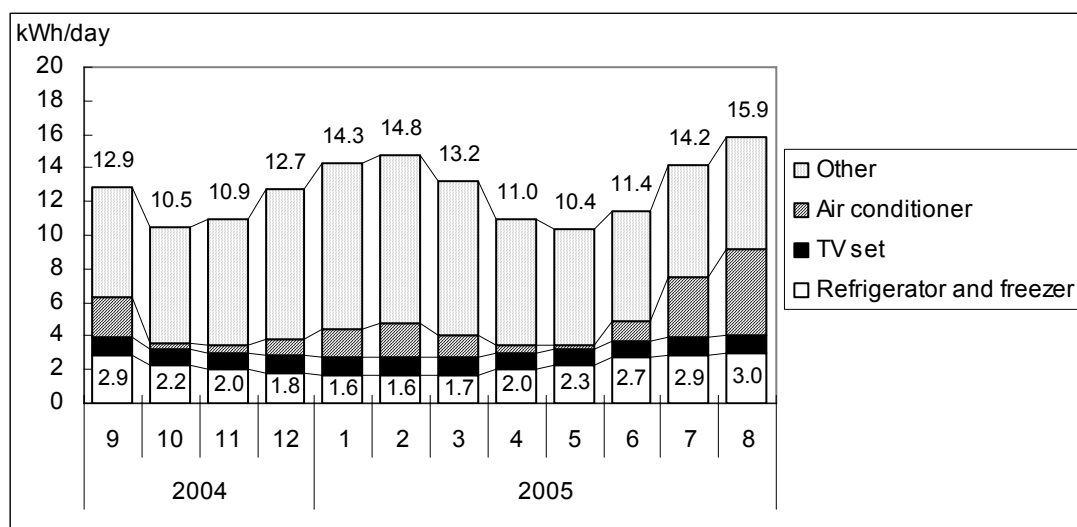


Figure 3. Monthly electricity consumption in monitored households

Unit electricity consumption (UEC) of refrigerators and freezers is shown in **Table 11**. The average UEC is 734 kWh/year, which is 65% larger than the labeled value. In particular, UEC of products manufactured between 2002 and 2004 is 662 kWh/year, which is almost twice as much as the labeled value.

It is evident that energy efficiency of refrigerators and freezers has improved. Average UEC of those products manufactured before the Top-Runner standard was established (subtotal of Testing Method A and Testing Method B) was 751 kWh/year. An improvement of over 10% was achieved in the few years since then, despite an 18% increase in storage capacity (from 325L to 383L).

Figure 4 shows the correlation between electricity consumption by refrigerators and freezers and room temperature by year of manufacture. When room temperature is over 20°C, the difference of electricity consumption is apparent. Electricity consumption increases by 5% when room temperature rises by one degree around 25°C.

Table 11. Comparison of measured electricity consumption and labeled value

Testing method	Year	UEC : Unit electricity consumption (kWh/unit/year)		Ratio of actual to labeled	Rated volume (L)	Room temperature (°C)	#
		actual	labeled				
A	'94	679	413	1.65	305	23.2	18
B	'95-'96	842	594	1.42	328	23.6	19
	'97-'98	733	420	1.74	337	23.7	23
Subtotal of A and B		751	473	1.59	325	23.5	60
C	'99-'01	720	416	1.73	392	24.7	14
	'02-'04	662	327	2.03	383	24.2	12
Total		734	443	1.65	344	23.8	86

Note: Test method was changed twice, so labeled values of one method can not be directly compared with those of another method (See **Table 2**).

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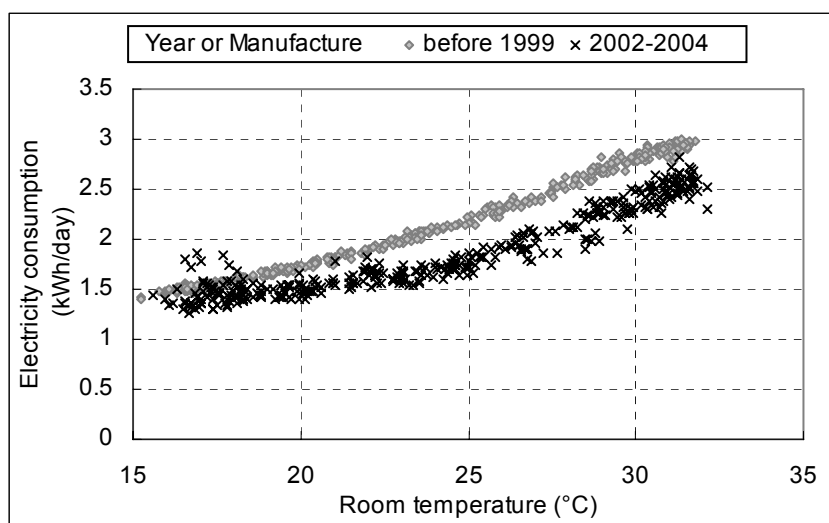


Figure 4. Correlation between electricity consumption by refrigerators and freezers and room temperature

Note: Data was collected from September 2004 to August 2005.

Lessons learned

Both the government and the manufacturers recognized the discrepancy between actual and labeled values of electricity consumption as a problem. The government began studying new testing procedures and new energy efficiency standards in September 2005.

As shown in **Table 12**, JIS C 9801 was revised by JIS Committee in January 2006 so that testing conditions more closely resembled actual use conditions. Two features of the revision are especially noteworthy: (1) two testing conditions (15°C and 30°C) and (2) the placement of load in the fresh food and freezer compartments in process of testing. It is considered that these complicated conditions make it virtually impossible for an embedded program to distinguish the testing from the actual use. The new value of annual electricity consumption is labeled on products manufactured after 1st May 2006 and new energy efficiency standards for refrigerators and freezers will be established by the end of the year.

Table 13 shows new labeled values of typical refrigerator-freezers. Comparing to the results of monitoring shown in **Table 11**, new test procedure seems to be more reasonable so far. In general, product testing procedure should be simple, but should not be at the expense of accuracy and credibility. It is strongly hoped that the revision of JIS testing procedure will restore the credibility of labeling and contribute to further energy efficiency.

Fortunately, remarkable difference in energy use between the actual and labeled has not been found in any other equipment. However, it is recommended that the government should check testing procedures of other equipments and carry out a continuous field survey on actual energy use of equipments including refrigerators and freezers.

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Table 12. Revision of JIS C 9801

		JIS C9801(old)		JIS C9801 (revised)	
Year		1999		2006	
Type		Forced circulation	Natural convection	Forced circulation	Natural convection
Ambient temperature		25°C		30°C : 180days 15°C : 185days	
Relative humidity		70%±5%		30°C : 70%±5% 15°C : 55%±5%	
Installation	back	On the wall		On the wall	
	sides	300mm away from walls		50mm away from walls	
Load	fresh food	No	No	Put in during testing	No
	freezer	No	Yes		Yes
Storage temperature	fresh food	≤ 5°C		≤ 4°C	
	freezer (***)	≤ -18°C		≤ -18°C	
	vegetable	Set to minimize energy use		Set to factory preset mode	
Open/close door	fresh food	25 times		35 times	No
	freezer	8 times		8 times	No
Automatic ice making		Off		On	Off
Other optional function such as deodorizing		Off (if users can turn on/off)		Set to factory preset mode	

Source: [4]

Table 13. Unit electricity consumption of refrigerator-freezer tested by revised JIS C 9801

Rated volume	UEC by revised JIS C 9801 (kWh/year)			Number of products
	minimum	average	maximum	
141L-200L	430	475	570	8
351L-400L	490	577	710	17
401L-450L	530	629	790	26
451L-500L	590	691	840	12

Source: The Japan Electrical Manufacturers' Association

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