APEC PROJECT EWG 4/99T

SYMPOSIUM ON

DOMESTIC REFRIGERATION APPLIANCES

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BACKGROUND DISCUSSION PAPER – MINIMUM ENERGY PERFORMANCE STANDARDS, ENERGY LABELLING & TEST PROCEDURES

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The Symposium

Objectives

The objectives of the colloquium are:

1. To consider the material concerning refrigerators and freezers in the *Review of Energy Efficiency Test Standards and Regulations in APEC Member Economies* and add to or update it where necessary;
2. To consider the benefits of, and barriers to, harmonising aspects of the energy test procedures and the development of a conversion algorithm for refrigerators and freezers.
3. Advise on the possible options for a “convergence and development strategy”.

Issues to be considered

Participants may wish to consider the following issues in relation to their economies, and come prepared to discuss them:

1. Is the material relating to refrigerators and freezers in the *Review of Energy Efficiency Test Standards and Regulations in APEC Member Economies* accurate for your economy? In particular, participants should review the sections on refrigerators and freezers for each economy (Chapter 2 of the *Review* - see Appendix 2 of this paper for a summary) and Annex A of the *Review*.
2. Are the inconsistencies between testing and energy labelling and MEPS requirements seen as a problem in your economy, from the point of view of (a) government and regulators, (b) product exporters, and (c) product importers? If there are barriers to trade caused by these inconsistencies, how can these best be addressed?
3. Would a greater degree of convergence be of benefit?
4. What aspects of the refrigerators and freezers energy testing and MEPS regime in your economy do you consider vital and should be retained?
5. What are your views on the convergence and development options outlined in this discussion paper? Do you have opinions on the use of the ISO standard and its requirements?
6. What is a realistic convergence and development strategy and timetable for test procedures?
7. Do you have other suggestions?

General Technical Issues to Consider:

1. Few international standards are currently "generic".
2. Climate considerations within test procedures.
3. How should test procedures deal with new "smart" products.
4. Full participation in international standards development.

Background - Trade Implications of Energy Programs

There is a significant amount of trade in energy-using equipment between APEC economies. A study of trade in air conditioners, refrigerators[1], electric motors and lighting products found that trade in refrigerators among APEC economies was worth about US$ 1,100 million in 1996 (APEC 1998)[2]. While this was the third most valuable of the 4 product categories studied, it still constitutes a major trade component within APEC.

World production of refrigerators was estimated to be 73 million units per annum in 1992 (Lebot & Waide, 1995): production within APEC was estimated to be nearly 40 million units in that year, or nearly 60% of world production. Of these, nearly 4 million units per year were traded amongst APEC economies in 1996 and a further 3 million were exported outside of APEC (ie some 35% of APEC refrigerator and freezer export production is destined for markets outside of APEC). Approximately 0.5 million units were imported into APEC.

This indicates that domestic refrigerator production probably accounts for some 80% of refrigerator sales within most APEC economies. This also suggests that international trade in refrigerators is currently limited, possibly because of the large number of test procedures in use.

Much of the refrigerator trade within APEC is affected in some way by minimum energy performance standards (MEPS). Imports in 1996 into APEC economies that have mandatory MEPS or energy labelling programs for refrigerators accounted for 63% of the value of intra-APEC refrigerator trade (APEC 1998). When voluntary energy related programs were taken into account, the proportion of trade affected climbed to 71%. A further 13% of trade could be potentially affected by programs under development or under consideration within APEC economies. Table 1 shows that by 1999 only a few APEC Economies did not have some energy related requirements for refrigerators. It important to note that Europe, which is responsible for 30% of world refrigerator production (but is not part of APEC), also has energy labelling and MEPS programs for refrigerators and freezers.

A traded product must comply with mandatory requirements in all the markets where it is sold, and the authorities in each market will usually ask for evidence that it does so. This means that a refrigerator exporter may need to have each model tested several times to demonstrate that it complies with the MEPS and/or energy labelling requirements in all the markets where it is sold.

The cost and time needed to comply with different energy efficiency programs can add significantly to the cost of traded refrigerators and can constitute a barrier to trade, especially if local testing is mandated as a pre-requisite for import. This is especially true for refrigerators which are generally both expensive and slow to test. While it is still likely that the benefits from lower energy use will outweigh the energy

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1 Refrigerators in this report should generally be taken to mean refrigerators, refrigerator-freezers and freezers unless otherwise noted.

2 Motors trade was worth US$ 2,500 – 3,000 million, refrigerator and freezer trade US$ 1,000 – 1,100 million, discharge and fluorescent lamps US$ 400 – 600 million and air conditioners US$ 3,000 – 3,300 million. The study was carried out before Peru, Russia and Vietnam joined APEC.

program costs, the cost-effectiveness of energy efficiency programs for APEC economies as a group would be higher if the compliance costs were minimised.

Compliance costs for traded refrigerators would be lowest if the following conditions were met:

1. All economies defined refrigerator product classes in the same way;
2. Alignment of test procedures for the measurement of refrigerator energy & performance;
3. Authorities accepted the same energy test results as proof of compliance with MEPS and energy labelling requirements, thus avoiding retesting;
4. All markets had identical MEPS requirements for each product class;
5. All energy labels were identical, so that the one label could be placed on the product as it left the factory, irrespective of where it was ultimately sold.

Clearly, these conditions are never likely to be met, nor are all of these necessarily desirable. For example, point 4 may result in sub-optimal economic conditions in some economies (as production costs, energy prices and climatic impacts vary considerable between economies), while point 5 would almost certainly create problems with respect to language, culture and consumer use and comprehension.

However, there are several practical options centred around points 1, 2 and 3 for reducing energy program compliance costs, to the benefit of all APEC economies participating in refrigerator trade. However, it would be fair to say that, for refrigerators, there is currently a very poor level of harmonisation within APEC economies with respect to test procedures for refrigerators.

Recent Review of Energy Test Standards and Regulations

The APEC Energy Working Group recently commissioned a review of energy efficiency test standards and regulations in APEC member economies (EES 1999). This surveyed a wide range of energy-using products, including refrigerators and freezers, and detailed the differences in product classifications, MEPS requirements, energy labels and energy test procedures between APEC economies.

Findings

The appendices attached to this discussion paper summarise the findings of the review with regard to refrigerators and freezers. These confirm that the energy program conditions affecting refrigerators trade do impose costs higher than the "ideal minimum", because:

1. There are a large number of different test procedures for the determination of refrigerator energy consumption - this generally requires re-testing for different economies (see Appendix 1 for a summary). There appear to be a number of local test procedures that have been independently developed;
2. Those economies with MEPS requirements for refrigerators and freezers (listed in Appendix 2) generally set different MEPS levels, even for the same product classes. Labelling requirements also vary considerably by economy, which is to be expected;

An outline of the types of refrigerator programs and their related test procedures currently in operation in APEC member economies is shown in the following tables. Table 1 provides an overview of program types for refrigerators and freezers for all APEC member economies.

Table 1: Summary of Refrigerator Labelling and MEPS programs by APEC Economy

	Australia	Brunei	Canada	Chile	China	Hong Kong, China	Indonesia	Japan	Korea	Malaysia	Mexico	New Zealand	Papua New Guinea	Peru	Philippines	Russia	Singapore	Chinese Taipei	Thailand	USA	Vietnam
Energy Labelling	M		M	U	U	V	V		M		M	V			M		V	V	M	M	U
MEPS/Other	M		M	U	M	U		T	M	U	M	U		U		M		M	U	M	U

M = mandatory, V = voluntary, U = under consideration, S = Singapore Accelerated Depreciation, T = Japan Top Runner Program

Some details of the type of specific programs for refrigerators and freezers are shown in Table 2. This shows the type of program and the year of implementation (where known) and any updates where applicable for relevant APEC economies.

Table 2 Refrigerator and freezer energy efficiency regulations by APEC Economy

	Program Type				
APEC Economy	**A. Comparison label**	**B. Endorsement label**	**C. MEPS**	**D. Industry target**	**E. Other**
Australia	M(1986)(a)	V(b)	M (1999, 2004?)		
Canada	M (1978)		M(1995)		
Chile	U		U		
China	M (UC)		M (1989)		
Hong Kong, China	V(1995, 1999), M(UC)		M(UC)		
Indonesia	V (1999)				
Japan				V (1979)(c)	T (2004)
Korea	M (1993)		M (1996, 1999)		
Malaysia			M (UC)		
Mexico	M (1995)	V (1997)	M (1995, 1997)		
New Zealand	V(1986), M(UC)(d)		M(UC)(d)		
Peru			U		
Philippines	M (target 1999)				
Russia			M (1987)		
Singapore		V (1998)			
Chinese Taipei	UC	V (e)	M (1996)		
Thailand	VH (1994) M (1999)		M (UC)		
USA	M (1979)	V (f)	M (1990, 1993, 2001)		

Source: EES, 1999. M = mandatory, V= voluntary program, UC = under consideration, T = Japanese Top Runner. Years in brackets indicate year of implementation plus updates where applicable.
Notes: (a) New comparative label design and grading scale to be introduced in 2000. (b) Galaxy label, Energy Smart label (mainly used in New South Wales). (c) Law Concerning the Rational Use of Energy, 1979. (d) Voluntary use of Australian energy labels; if RF MEPS implemented in NZ, Australian levels would probably be adopted. (e) Greenmark endorsement label. (f) EPA Energy Star label.

The refrigerator and freezer test procedures used in APEC member economies are shown in Table 3.

Table 3: Summary of test procedures used in APEC Economies

APEC Economy	Labelling and/or MEPS requirements	Local Test Procedures	Reference Test procedures, notes
Australia	AS/NZS 4474.2-1997	AS/NZS 4474.1-1997	ISO7371, ISO8561, ISO8187 and ISO5155, US DOE procedures
Canada	Regulations	CSA C300-M91	EQV USA DOE
China	GB 12021.2-89	GB/T8059.1 GB/T8059.2 GB/T8059.3 GB/T8059.4	ISO 7371 ISO 8187 ISO 5155 ISO 8561
Hong Kong, China	EMSD (1999)	EMSD (1999)	ISO 7371 ISO 8187 ISO 5155 ISO 8561
Indonesia	Local guidelines	ISO 7371-1995	
Japan	Regulations	JIS C9607 Method C	ISO 8561, but method different
Korea	MOCIE Rule 24 of 1999	KS C 9305-96	JIS C 9607, but method different, similar to Chinese Taipei
Mexico	NOM-015-ENER-1997	NOM-015-ENER-1997	EQV USA/Canada
New Zealand	AS/NZS 4474.2-1997	AS/NZS 4474.1-1997	ISO7371, ISO8561, ISO8187 and ISO5155, US DOE procedures
Peru		ISO 7371 ISO 5155 ISO 8561	
Philippines	Regulations	PNS 1475 PNS 1476 PNS 1477	ISO 7371 ISO 8187 ISO 8561
Russia	GOST 16317	GOST 16317 + others	Based on ISO
Singapore	Local Guidelines	ISO 8187 ISO 8561	
Chinese Taipei	File of (85) energy 84462391 issued by MOEA, 3 Jan 1996	CNS 9577-89 CNS 2062-95	Similar to Korea, diff. use of test packs
Thailand	Local Guidelines	TIS 455-2537	ISO 7371
USA	10CFR430 Subpart C 16CFR305 (labelling)	10CFR430 App A1	AHAM HRF-1-1979, minimal references

Refrigerator Testing & Actual Use

This section outlines a number of issues related to refrigerator testing and use which are relevant for consideration at the APEC Symposium.

Ambient temperature for test

There is currently a large degree of “disharmony” with respect to refrigerator test procedures around the world, where ISO specifies 25°C ambient (for temperate) or 32°C (tropical), USA and AS/NZS specify around 32°C ambient while Korea and Chinese Taipei specify 30°C ambient. The JIS Standard previously specified energy measurements at 30°C and 15°C with door openings and freezer test packs, but this standard was discontinued in favour of ISO and more recently the ISO version been amended to a single temperature 25°C ambient with door openings but without test packs for forced air (test packs for natural convection). There are also differing internal temperature requirements for various standards - these are outlined in Appendix 1.

The nub of the problem is that a refrigerator is a thermodynamic appliance and has to operate under a range of ambient temperatures during normal use and its performance and energy consumption will vary under varying conditions. A static test at a single temperature without door openings (which is the basis for most current refrigerator tests) will not provide accurate data on how a refrigerator is likely to perform under a range of normal ambient conditions. The slope of the energy-ambient temperature performance profile for each refrigerator model will differ and it is not possible to estimate this function from a single static test point (see section below on *Selected refrigerator test data*). In this respect, all existing refrigerator test procedures are inadequate, at least to some degree.

Energy test data used for regulatory purposes appears to have two main functions. The first is to specify a minimum efficiency requirement for a product via a MEPS level. Typically this is expressed as a maximum allowable energy consumption based on the model's attributes such as volume, features, defrost type plus other factors. The purpose of MEPS is to eliminate models of low efficiency, so it is of little concern or consequence if the method of test used to determine whether a model passes MEPS is reflective of actual use.

The second main use of energy test data for regulatory purposes is for energy labelling. The goal of an energy labelling program should be to encourage consumers to purchase the appliance that (1) uses the least energy and (2) meets their energy (service) needs. Using least energy is an important point, because it necessarily relates to the way in which a consumer uses their appliance. It would be of little value (or even misleading) if an energy label ranked a number of models according to a test procedure but that their energy ranking in actual use was different (assuming the provision of comparable energy service).

Much of the debate with respect to ambient test temperature centres around the issue of what is the "most" reflective of actual consumer use. This is a complex issue and the short answer is that no single temperature is really appropriate for everyone. Clearly, actual use in Thailand, Philippines or the Pacific Islands will be very different to Australia, Canada, France or Sweden. There is even some evidence from end use monitoring programs that refrigerator in use energy consumption in colder climates such as Canada and Sweden is higher than in more temperate climates because there is a much higher prevalence and degree of space heating during the very cold winter months. For example, many houses in Australia only space condition a small zone in their houses in winter and summer as the climate is relatively mild in most parts of the country for much of the time and therefore building thermal construction standards have tended to be relatively poor. So a refrigerator operating in an Australian house may be subjected to a much higher diurnal or seasonal temperature range than say one in either Sweden or Thailand.

If all refrigerators had a similar energy-temperature performance profile or if all households experienced the same average internal temperatures, there would be little problem. However, the "average" temperature experienced in a consumer's home will vary by economy and may even vary enormously within an economy such as Australia which has climate ranges from cool temperature to tropical (noting that many tropical household have neither space heating nor cooling appliances). As stated previously, refrigerators are a dynamic product and the energy-temperature profile of each model can be quite different (see the section below on *Dual temperature test data* and Figure 11 - this shows that energy consumption variations per degree C between 16^{o}C and 25^{o}C vary by a factor of three for the same sized cabinets). This means that a single temperature test point is of little benefit in terms of advising consumers how to rank models in terms of their energy performance (old engineer's saying: *you can't determine the slope of a line from a single point*).

A more suitable arrangement would be to undertake energy consumption tests at dual temperatures such was undertaken in previous Japanese standard (Method A). The ambient test temperatures selected in the previous Japanese test procedure (15^{o}C and 30^{o}C) seem to be very sensible in that they lie at the likely end of realistic internal household temperature experienced for a range of climates. The only serious point of contention or likely resistance regarding the Japanese test procedure (in terms of traditional refrigerator testing) is the use of door openings during the test and their attendant problems (see following section).

Perhaps and ideal method of test would be undertake dual temperature testing for energy with additional tests using controlled internal heat loads to simulate warm food loads and introduction of humidity to simulate door openings and defrost performance. Such points could be weighted in proportion to the likely temperature range experienced by consumers to give a much more accurate estimate of in use energy consumption on an energy label (assuming a linear energy profile). This could even form the basis of advisory data within different climate regions of an economy. Such tests could also form the basis of the physical tests to calibrate a computer simulation model. No doubt there are many things regarding ambient test temperature that could be discussed in more detail.

Door openings

Door openings have always been controversial to some degree in refrigerator testing circles. The arguments in favour of door openings are that this is more reflective of actual consumer use in terms of introduced heat loads from the ingress of ambient air and introduction of humidity into the compartments. The argument against door openings is that this introduces into the test method a great deal of difficulty and cost - accurate control of humidity in the test room and equipment for opening the doors at specified times and rates. It also is likely to make the test result somewhat less repeatable as it is difficult to replicate the test conditions precisely. The other argument against door openings is that the frequency and duration of opening specified in a test is likely to be highly arbitrary - no consumers will of course open the doors for the same frequency and duration as specified a particular test method, nor will actual consumer room conditions be the same as the ambient test conditions. Another argument is that many believe that the major heat load introduced into refrigerators is warm food rather than warm air (which has a low thermal mass), so door openings may underestimate real introduced heat loads in any case.

One option, which is yet to be developed in detail, is the use of controlled internal heat loads within the refrigerator (such as a calibrated 10W or 20W heat, for example). The refrigerator could undergo a static test without the internal heat load and then again with the internal load. These test points would provide data on the refrigerators ability to remove introduced heat from the cabinet under a range of heat load conditions. Similarly, a controlled method of introducing humidity into compartments could be developed to enable the defrost-energy performance to be developed. These additional tests, combined with test measurements at two ambient temperatures, would give a could deal of performance data on which to simulate the refrigerator energy performance under a range of ambient and usage conditions.

Freezer test packs for energy tests

The inclusion of freezer test packs during the energy consumption test appears to be another issue that is somewhat controversial. Test packs in the freezer are intended to simulate ballast or food loads in the freezer compartment during the test, so in this respect they are intended to simulate actual use, at least to some degree (although there are very few consumers that actually fill their freezers with bags of oxyethylmethylcellulose!).

During a normal energy consumption test, it is usual to ensure that the defrost system is connected and operating normally. The problem with freezer test packages in the freezer during a defrost cycle is that it can put the freezer compartment (and indeed the whole refrigerator) out of thermal equilibrium for a short period, which can create stability and repeatability problems. The exact placement of the test packs relative to the defrost system can also be critical. Normal practice in North America, Australia, NZ, Korea, Chinese Taipei and Japan is now to remove freezer test packages during an energy consumption test, at least for frost free (forced air) types where the freezer compartment will undergo automatic defrost cycles. The markets in these economies are dominated by frost free appliances and their extensive experience in this matter would tend to suggest that this practice is necessary for a repeatable result.

The presence (or otherwise) of test packages in the freezer compartment for manual defrost models is unlikely to have a large effect on performance of a refrigerator, although it will make some difference to absolute results by dampening temperature shifts in the freezer during compressor cycles. Of course the method of temperature measurement in the compartment is quite different for test packs versus air. In Australia and New Zealand, all models are tested for energy consumption without freezer test packages on the basis of consistency (all defrost technologies are treated in the same fashion). In Japan test packages are eliminated only for forced air types.

ISO specify that test packs are used for energy consumption tests. The ISO standards also specify that the test packs should be loaded up so that they are touching the walls of the freezer compartment, which is considered by many to be dubious practice. The ISO committee has traditionally been dominated by Europeans, who until now have had very little experience with frost free technology, so it is perhaps open to question whether their decision to include test packs for energy tests (and the required loading pattern) is based on sound and extensive experience.

All test procedures use test packages for temperature operation tests which check the stability and balance of internal temperature inside a refrigerator-freezer, but ironically, this is normally undertaken with the defrost system inoperative (due to stability and equilibrium problems). Most test procedures specify air gaps around the test packages for frost free freezer types, except for ISO which specifies that the test packages should be in contact with the freezer walls.

Almost all test procedures in use today specify ISO type test packages (made of oxyethylmethylcellulose) wherever test packages are required (see Appendix 3 for a detailed definition). The main exception is in North America which specify test packages made of hardwood sawdust or spinach. It is unknown whether spinach and sawdust exhibit different performance properties (from each other or from ISO test packs) during a test. It would seem sensible for North America to eventually move to ISO test packages when an opportunity arises.

The issue of the use test packages is somewhat vexed and could no doubt generate a good deal of debate.

A related issue is the determination of compartment temperatures - ISO specify warmest temperature of the warmest test pack while other standards specify various average values - some reconciliation of approach would be beneficial.

Selected refrigerator end use test data

There are few examples where in-use measurement of energy consumption has been compared with the measured value on an energy label. One data source is a project undertaken by Australian Consumers Association where 25 refrigerators were laboratory tested and then installed in households for 2 years. The units were tested in the laboratory again after one year and then again after 2 years (ACA 1990). In-use energy consumption was metered quarterly for 9 of the models. The general findings were that for refrigerators in NSW, the energy label test (ie 32^{o}C ambient test) over-estimates the in-use energy consumption by about 10% to 20%. Summary of the models tested are shown in Table 4.

Table 4: Tested versus In-Use Energy Consumption - NSW

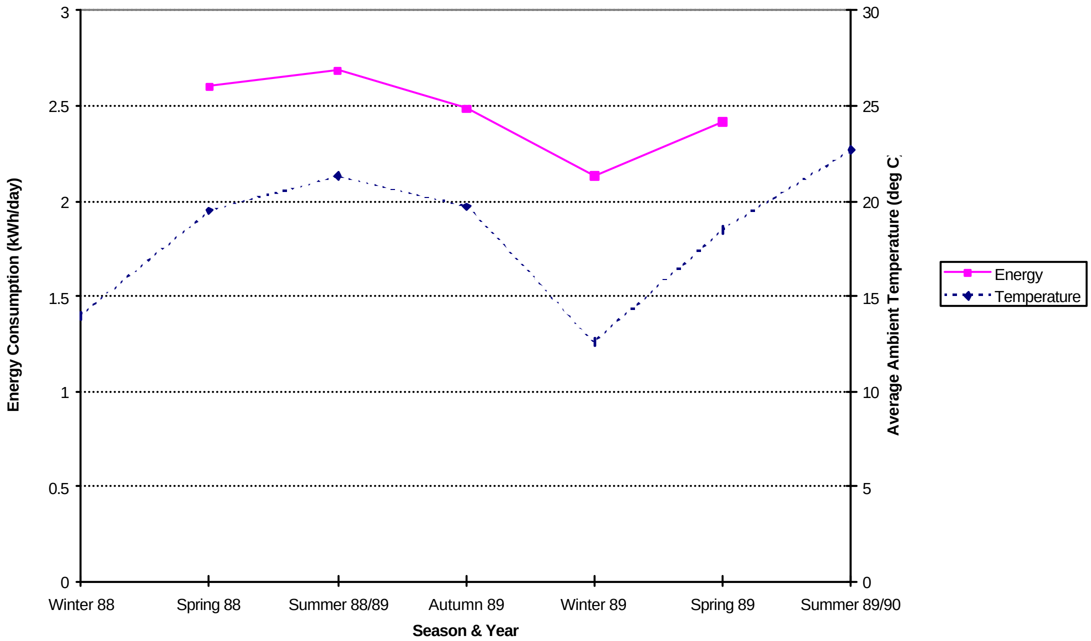
Model	Group	Tested Energy	Measured Year 1	Measured Year 2	Average kWh/day	Ratio test/in-use
NE1	2	1.493		0.900	0.900	60%
KE3	4	2.783	2.630	2.360	2.495	90%
PH2	4	2.577	1.650		1.650	64%
KE6	5	3.243	2.540	2.810	2.675	82%
M11	5	2.220	1.790	2.120	1.955	88%
PA2	5	3.940		3.490	3.490	89%
PH4	5	2.613	2.490	2.400	2.445	94%
SI2	5	4.693	4.050	3.590	3.820	81%
WE1	6	1.123	0.730	0.790	0.760	68%

Source: ACA (1990). Measurements were taken over the period 1988 to 1990.
Standard test conditions were at 32^{o}C ambient temperature to AS standard.
Group 2 = refrigerator + icebox, Group 4 = refrigerator-freezer (cyclic/manual)
Group 5 refrigerator-freezer (frost free), Group 6 = upright freezer (manual defrost)

Some data is missing due to faulty meters. Interestingly, the energy consumption results for the laboratory tests were highly repeatable over the 3 year period, with a standard deviation of the 3 measurements being less than 2% of energy for all but one unit (which recorded 5% standard deviation due to an increase in energy consumption over the two years from 1.42 kWh/day to 1.56 kWh/day). This tends to confirm the view that in most cases there is no obvious degradation in energy performance of refrigerators, at least in the short term.

It would appear that the in-use energy consumption of freezers is much lower than determined under standard conditions (32^{o}C). The data for model PH2 was not listed by season, so this annual figure may be suspect. The overall seasonal impact of energy consumption on these refrigerators is shown in Figure 1 (although the energy curve is based on a small sample in some cases, so care is required).

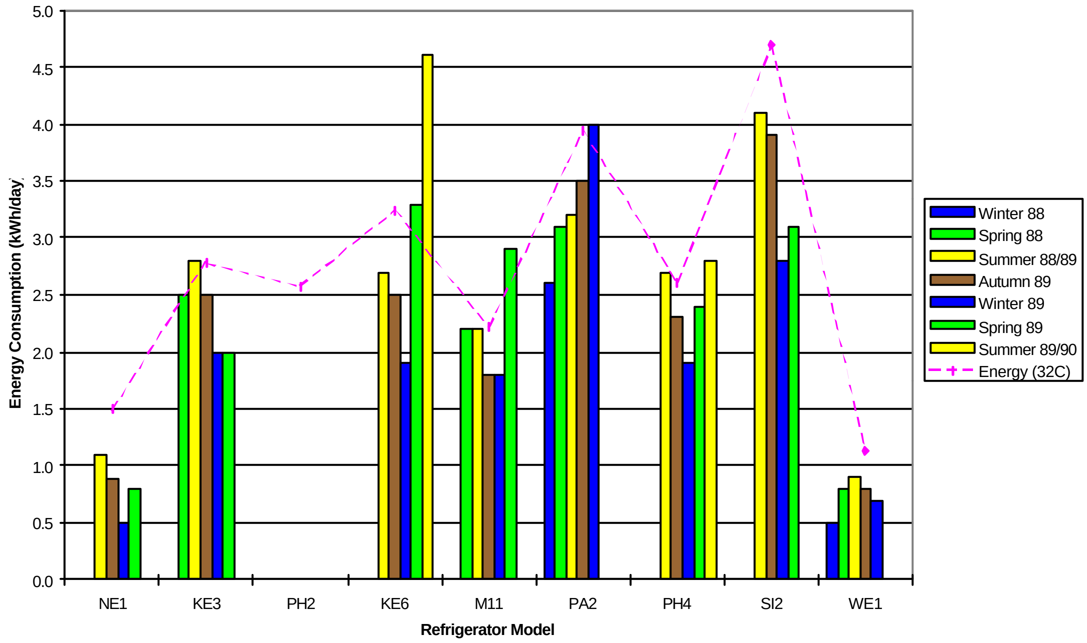
Figure 1: Seasonal Variation of Energy and Temperature - NSW



Source: ACA (1990) and author analysis

ACA data also shows that seasonal energy consumption of refrigerators varies considerably. Seasonal data by model, together with the energy determined under standard conditions is shown in Figure 2. It would appear that the energy consumption under standard conditions is similar to the peak summer consumption in many cases, but the average ambient temperature in summer is considerably lower than the test conditions of 32^{o}C, indicating that food loads and door openings may have a significant impact on energy.

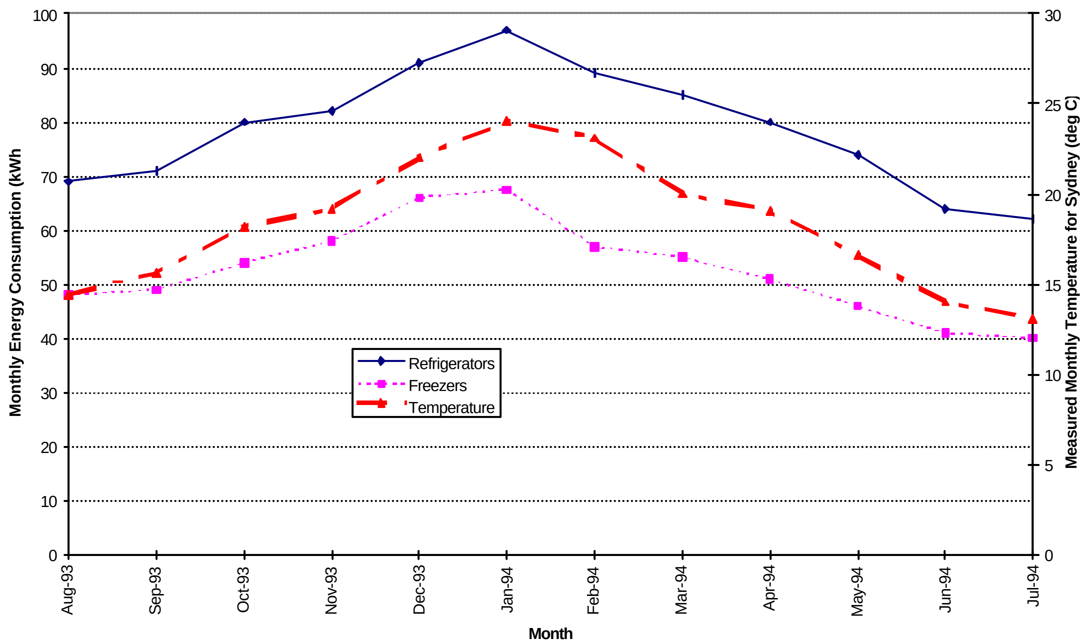
Figure 2: Seasonal and Tested Energy Consumption by Model - NSW



Source: ACA (1990) and author analysis

Another source is the Pacific Power Residential End-Use Study (Pacific Power 1996). The raw data contains actual in-use information for some 327 refrigerators and freezers for a period of about 18 months from early 1993 to mid 1994. However, the raw data is not yet available (the data is being analysed and results are expected in mid 2000) but energy labelling data for the units is not available.

Figure 3: Monthly Variation of Energy Consumption - NSW

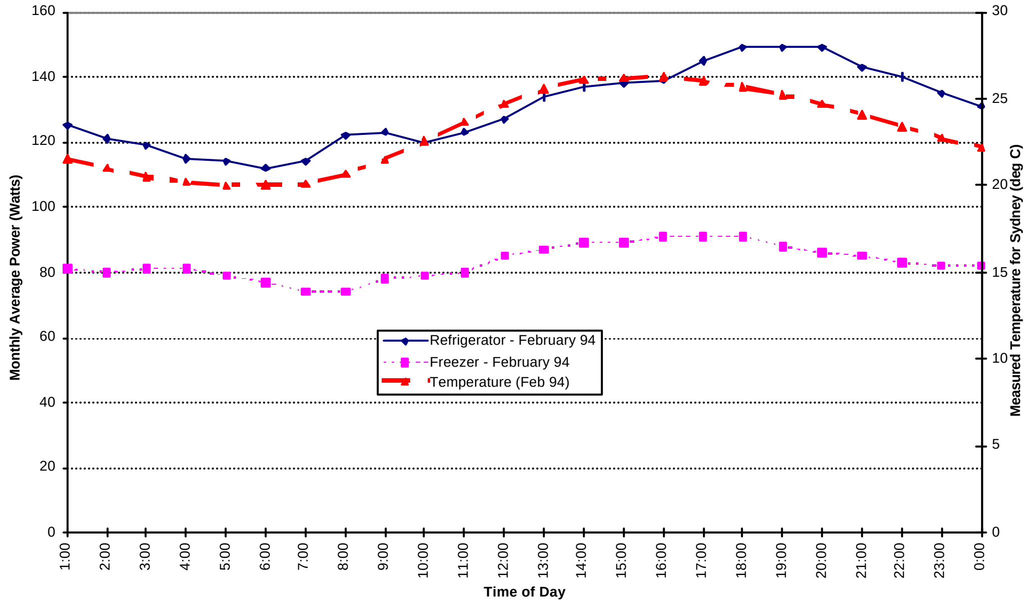


Source: Pacific Power (1996) and EES (1998)

Data from the main report (Pacific Power 1996) shows seasonal variation of energy consumption for refrigerators and freezers (see Figure 3).

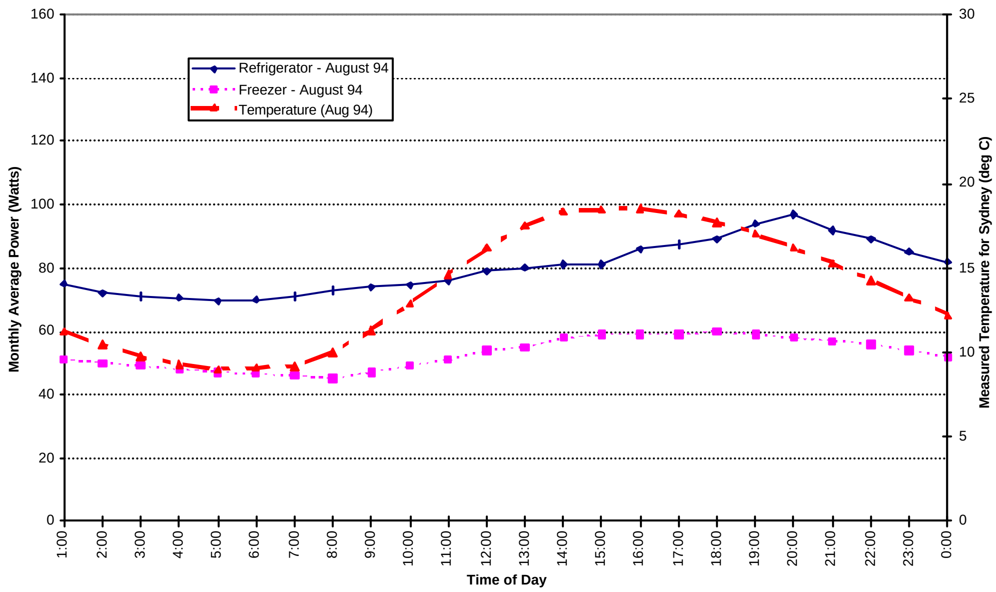
Note that the temperature data is actual average monthly figures for Sydney based on hourly estimates from the Bureau of Meteorology for the same period. However, some of the sample were outside of the Sydney area. The sample size for refrigerators was 219 and for freezers it was 108.

Figure 4: Daily Variation of Energy Consumption (February 1994) - NSW



Source: Pacific Power (1996) and EES (1998)

Figure 5: Daily Variation of Energy Consumption (August 1994) - NSW



Source: Pacific Power (1996) and EES (1998)

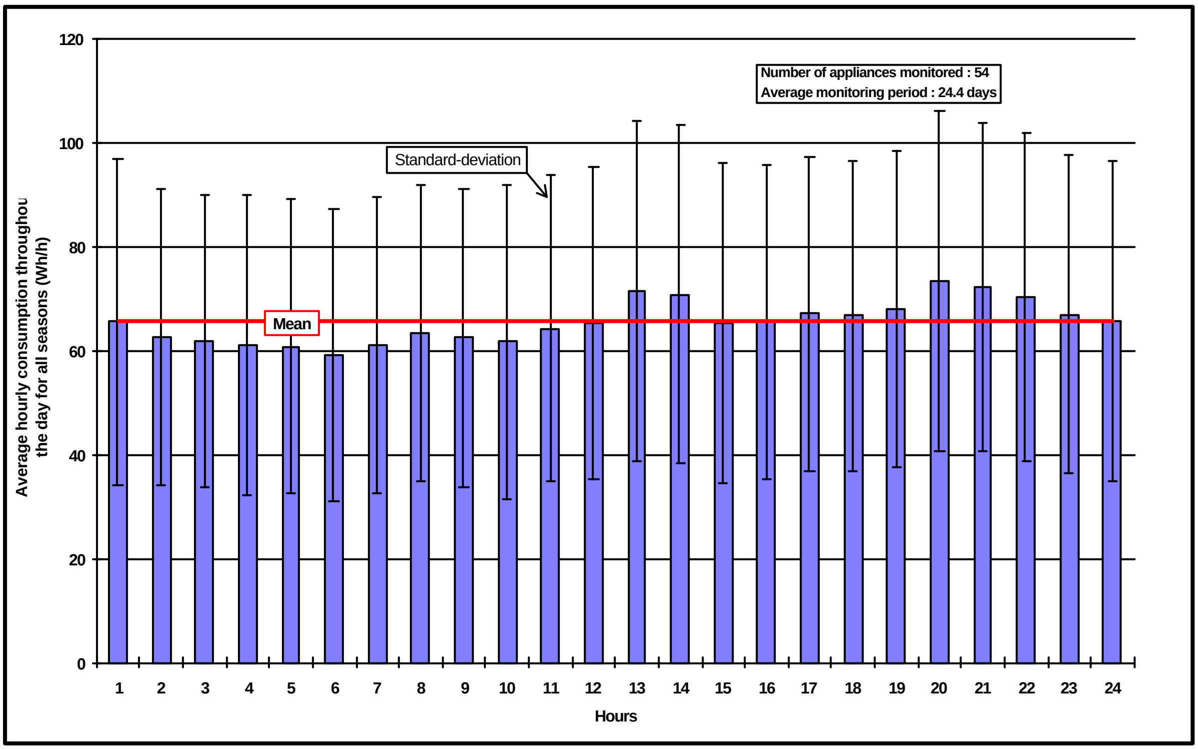
Data on the time of use of refrigerators and freezers for February 1994 and August 1994 are shown in Figure 4 and Figure 5. Clearly energy consumption is highly correlated to outdoor temperature for both months, although the diurnal variation in energy during August is lower than February as the external temperature is closer to the internal refrigerator temperature which means dramatically reduced heat gain. However, there will be some space heating in August, in the evenings in particular. Note also that inside temperatures are likely to lag outdoor temperatures and that indoor temperature variations will be less than outdoor (as a result of building shell thermal mass and insulation and space heating and cooling).

The peak demand for both refrigerators and freezers occurs in the evening for both months during the period of peak use of the appliance (ie 18:00 to 21:00 hours), indicating that door openings and to some degree, space conditioning, are having some impact on energy consumption patterns.

There have been some extensive end use monitoring programs in Europe, one of which was undertaken in France (Sidler 1997). While some 130 refrigerators and freezers were monitored under this program, most of these are for a period of less than 1 month (25 days average), so that seasonal data cannot be estimated directly. Unfortunately, there was also little data available on the claimed energy rating of refrigerators monitored, as the measurements were undertaken substantially before energy labelling was introduced in Europe. However, the report concludes for refrigerators (single door) and freezers, that the in-use energy consumption is somewhat less than that declared on the energy label which is measured under ISO (25^{o}C ambient). No conclusions for refrigerator-freezers were possible due to lack of data. Some further extensive end use monitoring and analysis has been undertaken in recent years but the results are not yet available in English - expected later in 2000.

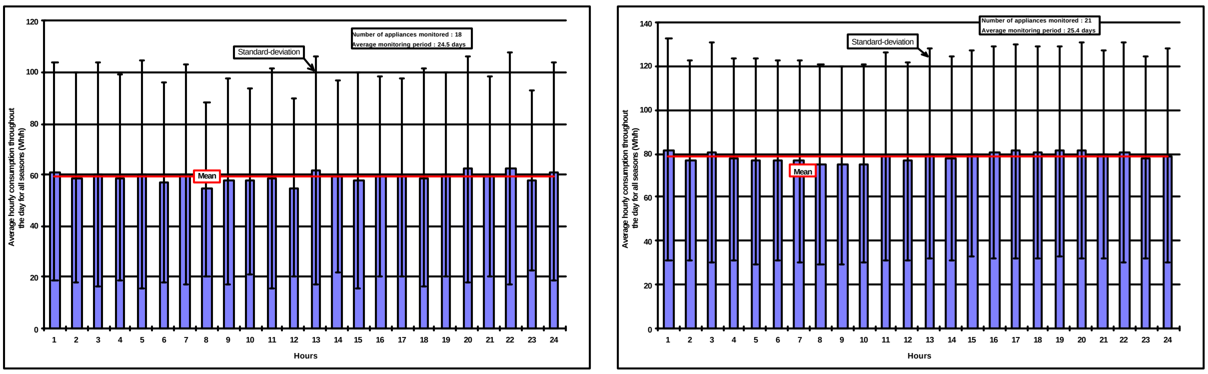
An excerpt on refrigerators from Sidler (1997) is attached. This shows the daily variation of energy consumption for refrigerators and freezers monitored. Refrigerators and refrigerator-freezers show significant hourly variation, while freezers show little variation. This confirms that freezers are both less affected by variations in ambient temperature and are probably subject to fewer door openings. This data is broadly consistent with Pacific Power (1996).

Figure 6: Daily Variation of Refrigerator-Freezer Energy Consumption (France)



Source: Sidler (1997)
Note: Large standard deviation is a result of seasonal variations - most appliances are monitored for only one month. Hourly variation is a result of temperature variations and door openings/food loads.

Figure 7: Daily Variation of Freezer Energy Consumption (France)

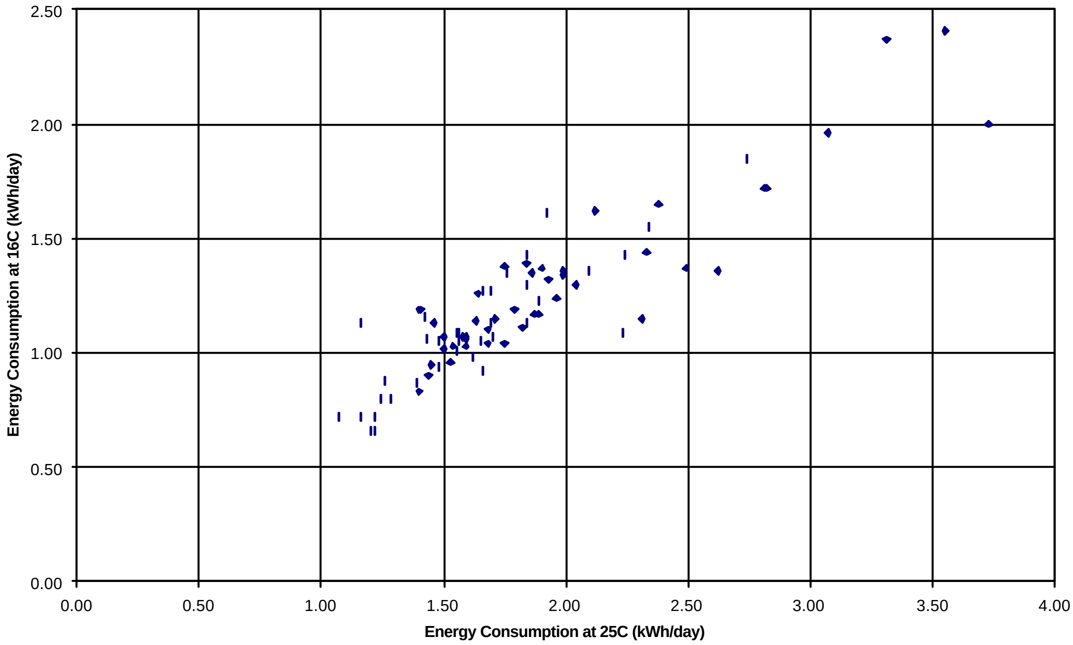


Source: Sidler (1997)
Note: Large standard deviation is a result of seasonal variations - most appliances are monitored for only one month. Chest freezers are on the left and vertical freezers on the right.

Dual temperature test data

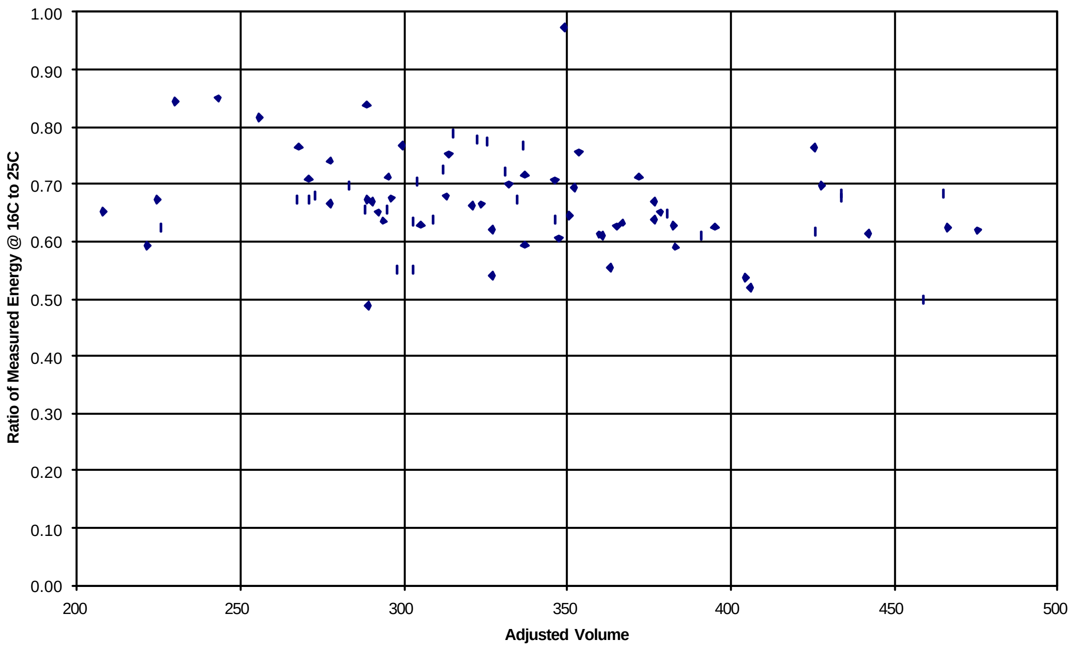
Another useful source is a database of energy consumption of refrigerators in Europe for both 16^{o}C and 25^{o}C which was recorded in 1992 by the Consumers Association of the UK during their appliance testing programs (Waide 1992). Data for some 100 freezers and 90 refrigerator-freezers (2 door) was made available for analysis. The results are shown in Figure 8 to Figure 11).

Figure 8: European Refrigerator-Freezers: Energy at 25°C versus 16°C



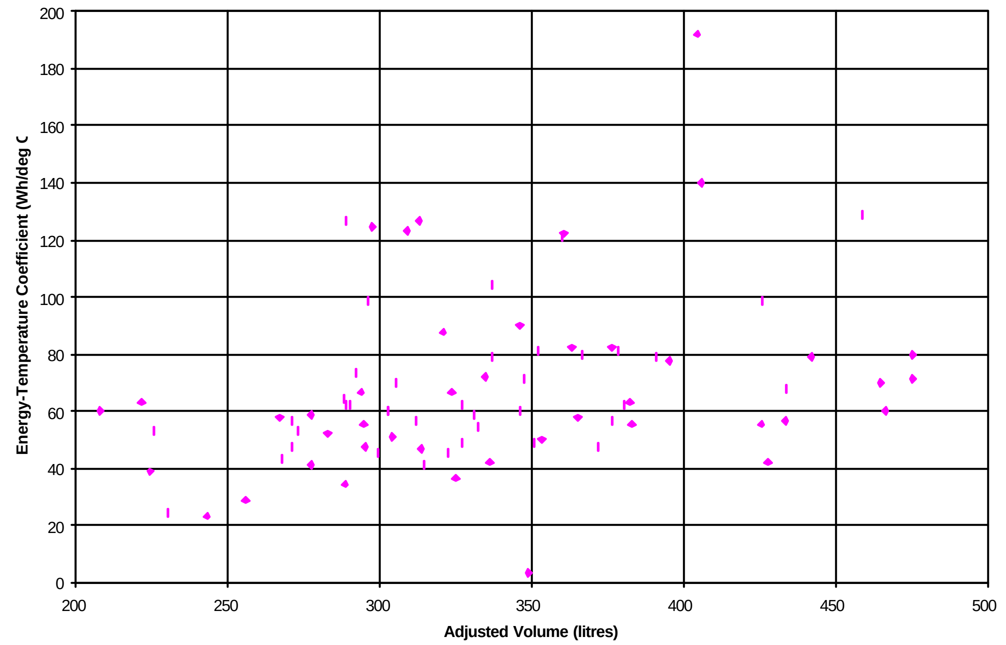
Source: Author analysis basis on data in Waide (1992)

Figure 9: European Refrigerator-Freezers: Energy Ratio versus Adjusted Volume



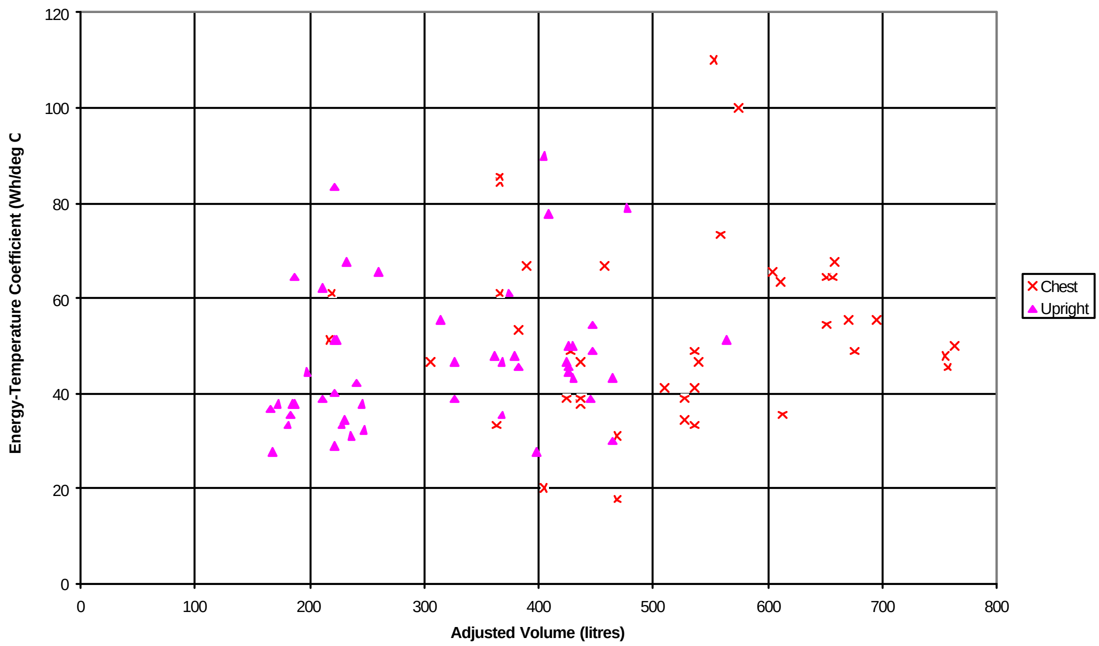
Source: Author analysis basis on data in Waide (1992). Note FAF = 2.15 for Europe.

Figure 10: European Refrigerator-Freezers: Energy-Temperature Coefficients



Source: Author analysis basis on data in Waide (1992). Note FAF = 2.15 for Europe.

Figure 11: European Freezers: Energy-Temperature Coefficients



Source: Author analysis basis on data in Waide (1992). Note FAF = 2.15 for Europe.

This data shows that the energy-temperature coefficient for refrigerator-freezers and separate freezers varies enormously between models (by a factor of three or four in some cases for models of the same volume), so that accurate in-use energy consumption would be impossible to estimate from energy consumption measurements at a single temperature (even where indoor temperature profiles are known). Note that measurement of energy consumption at a single ambient temperature is the method currently used by all national and international test procedures.

General Issues for Discussion

Few international test procedures are "Generic"

Despite the best intentions and efforts of standards committees and their members, the reality is that few, if any, of the commonly used international test procedures, are in a form that could be considered "generic", in that they can characterise the product under a range of typical uses. For some products, such a "generic" test procedure is quite feasible, but for others (such as refrigerators), the prospects of a generic test procedure are probably poor. In these cases, a conversion algorithm (or computer model) may be a more suitable option.

Climate considerations

Climatic considerations are critical for some products (especially refrigerators), and this is generally poorly handled in the existing test procedures for these product types. These products, which typically have widely varying temperature performance coefficients for different models, are usually tested under a single static temperature condition, which is neither representative nor facilitates the estimation of performance under other conditions (including actual use). Of course, "actual use" and a "representative test point" can never be developed – consider an economy such as Australia which has climate zones ranging from cool temperature to humid tropical; a single test condition can never be representative of such a range. For such products, a complex conversion algorithm (ie computer model) is probably the only feasible long term option.

New "Smart" Products

The increasing prevalence of electronic controls in appliances and equipment will make testing more complicated and less repeatable. Features such as fuzzy logic, automatic programs and sensors are becoming common. It is therefore important that test procedures move with the times to ensure that these smart products don't outsmart the test procedures.

A related issue is that where a test procedure specifies a single test point (eg refrigerators), it is well known that manufacturers tend to optimise for that test point rather than for real consumer use. This is of little service to the consumers who are supposed to be helped by programs such as energy labelling. Examining energy and performance over a range of conditions (which would typically need to be done in the development of a conversion algorithm) means that there is no advantage for manufacturers to optimise to a test single condition, hence products would hopefully become more versatile and better optimised for real use.

Global international standards

More often than not, international standards committees draw expertise from a narrow base of economies. Many committees which cover energy and performance of products draw heavily from European economies, while input from outside of Europe (including APEC) is usually minimal, if non existent. While it is fair to say (and it is often said) that many of these standard committees are dominated by Europe, it is also fair to say that few APEC economies (or those from other regions) provide any significant input or resources into these areas. So European domination, as such, tends to be by default rather through any systematic plan or conspiracy. Another problem area is that the composition of international standards committees tends to be from manufacturers and to a lesser degree material suppliers and test laboratories. Ironically, there is often a low level of input from regulatory agencies, who in fact are often charged with the ultimate use of these test procedures. If international standards are to become more relevant, regulators will need to provide coherent input and ongoing development resources into these areas.

Conversion algorithms or alignment?

The development of conversion algorithms has, in effect, the same impact as the alignment of test procedures – it avoids having to retest an exported product to range of local test procedures. So really, either alignment of test procedures or development of suitable conversion algorithms provides an acceptable outcome in terms of APEC policy requirements and future directions (provided that economies accept the results of a conversion algorithm as credible).

In summary the benefits are to:

- facilitate international trade
- decrease testing and approval costs for manufacturers
- allow the free movement of the most efficient products (noting that products with a low energy efficiency may still be barred if they do not meet local MEPS levels)
- facilitate international comparisons
- assist in the diffusion of advanced energy saving technologies.

Conversion algorithms have the advantage of being able to provide a more accurate estimate of the impact of local usage patterns, better ranking of products under conditions of actual use and may also allow the retention of local or traditional test conditions for programs such as MEPS. However, in cases where a particular product test procedure is clearly technically superior and already characterises products to the level that is necessary, alignment would probably be a preferable medium term option. It is only worth aligning with a standard that is technically superior and competent – aligning to a poor test procedure serves little purpose.

In terms of possible options for refrigerators and freezers, the prospects are currently not very encouraging:

- there are a large number of test procedures in use around the world and many of these have fundamental differences which make it difficult, if not impossible to determine levels of equivalence between them (particularly given the way the data is currently recorded and the suite of tests required) - none of the current methods in use is clearly more superior to the others, which makes selection of one existing method over another somewhat arbitrary;

- test procedures are generally not very reflective of actual use and it is difficult to provide consumers with realistic advice on model selection using the current test results (ranking may change substantially depending on actual conditions of use);
- there are currently no substantive algorithm or computer modelling options that are sufficiently well developed to take the place of current test procedures and to provide conversions between them - development of such options would be a substantial task;
- a large number of APEC (and other) economies regulate refrigerators and freezers for energy efficiency and as such there is substantial regulatory "baggage" or "inertia" built into the current test methods (changing the test method may mean complete revision of MEPS lines and/or energy labelling requirements, which is potentially disruptive and may be costly to both governments and industry).

APEC Report Recommendations for Refrigerators

The APEC study made the following recommendations regarding refrigerators.

Overview

Although refrigerators and freezers are produced in very large numbers, there has only been limited inter-regional trade in finished products until recently. This pattern is changing as manufacturers are increasingly moving beyond their traditional market boundaries and are either exporting their products, or more commonly, initiating manufacture in target export markets. Some APEC member economies use the ISO test procedures that are also used in Europe but there are a large number of economies that either use totally different test procedures or use procedures that only partially concur with ISO. None of the existing test procedures is clearly superior to the others and each represents trade-offs between ease of use, repeatability and reproducibility, cost and accuracy in representing performance during actual use.

Many APEC economies, as is the case around the world, regulate refrigerators and freezers for energy efficiency or include these in energy related programs. Refrigerators are probably the most regulated product within APEC (and in the world) with respect to energy efficiency and yet it is probably the product that has the most complex and diverse range of test procedures (sometimes with valid reasons) and therefore possibly the worst prospects for either alignment or conversion algorithms. Refrigerators are one of the most common products, both in businesses and households, and is one of the most affected in terms of energy consumption with respect to climatic and temperature conditions, which vary considerably by region.

Test procedure differences and limitations

The main differences in the major test procedures are for the choice of ambient temperature used for the steady state energy test, the interior design operating temperatures, the method of measuring the interior operating temperatures, whether frozen food compartments are loaded or not and whether door openings are included or not. The ambient test temperature is 25°C in ISO (or 32°C if the unit is rated as a tropical class appliance), 32.2 °C under ANSI/AHAM and 32°C in AS/NZS. In Japan energy consumption is now tested at 25°C with door openings. Chinese Taipei and

Korea use an ambient of 30°C. Significant differences exist in the interior temperatures such that under ISO and JIS the fresh food compartment is 5°C, and the frozen food compartments either -6°C, -12°C or -18°C, while in the ANSI/AHAM the frozen food compartment is –17.8°C for a deep freezer but only -15 °C for a refrigerator-freezer frozen food compartment. Similar differences exist with the other procedures. As products are generally designed to perform best under the local test procedures, there is a significant difference between and difficulty in comparing the performance provided.

Other subtle differences exist which can have a major bearing on the rated energy consumption. The most important are whether the freezer compartment is loaded (as in ISO) or not (as in AS/NZS and CNS and KS) (or only sometimes as in North America and JIS Method C) and how the compartment temperature is defined and the test packages placed. For the latter, ISO is most concerned about ensuring that a minimum temperature performance is maintained for frozen food compartments and thus defines the compartment temperature as the highest temperature of the warmest test pack, as opposed to the AS/NZS which defines the compartment temperature as the average of all the temperature sensors in the non-loaded compartment (average of the warmest 4 of the 5 sensors). These differences mean that it is extremely difficult to directly compare compartment operating temperatures. It is likely that the ISO test procedures will be less reproducible than the procedures that don't use freezer packs but it could be argued that they are more representative of actual usage conditions and give better guarantees of minimum temperature performance (although temperature performance is measured by a separate test). The reproducibility of the ISO procedure is particularly in doubt for no-frost (forced-air) freezer compartments as it requires the freezer compartment to be fully loaded during testing with test packs touching the walls, which necessarily leads to significant potential variations in convective heat transfer. Another important issue is the treatment of non-energy performance. The US DOE's interpretation of the ANSI/AHAM standard sets no non-energy performance requirements and thus manufacturers can optimise their products' performance to the single set of steady state conditions required under the energy test. This is not so simple under the ISO, JIS, KS, CNS or AS/NZS tests as these also require various temperature and freezing performance tests to be passed which will necessarily make it more difficult to optimise the system performance to a single set of rating conditions. This is particularly true for refrigerator-freezers where ensuring the interior design temperature can be maintained under a wide range of ambient temperatures imposes severe constraints on the system balance.

Another key issue is the treatment of auxiliary energy loads and in particular the defrosting system. None of the existing procedures will reward adaptive defrost systems correctly, for example, and there are some important differences in how the defrost cycle should be initiated[3]. Lastly, the JIS procedure is the only one which uses door openings, which as it is performed under controlled humidity conditions, perhaps better represents actual ice build up and hence defrosting loads. But this is expensive and difficult to perform and may in fact reduce repeatability.

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3 In fact, adaptive defrost is a good example of how smart controls and electronics can result in real energy savings in an appliance, but testing the product becomes more difficult (as the behaviour under test may change each time as the appliances assesses the conditions) and estimating the actual energy savings in actual use (rather than under test) is difficult (may require some elaborate in use monitoring).

The ANSI/AHAM test procedure is likely to be quite reproducible but this is arguably achieved at the expense of over simplifying performance and involves some quite crude corrections (e.g. freezer energy consumption is reduced via a simple correction factor after measurement to give a more realistic in-use energy consumption – presumably this was obtained through empirical means). The older JIS standard has unloaded freezer compartments, door openings and two ambient temperatures but is comparatively expensive and perhaps less reproducible than ANSI/AHAM. The ISO standards fall somewhere in between these ranges. The AS/NZS standard has been shown to be highly reproducible. The new JIS standard sometimes has freezer test packs sometimes and door openings with a single ambient temperature. In reality all the test procedures are a considerable simplification of reality as no cold appliance is ever operated under steady state environmental conditions for very long and none of them address warm food loading (except through the freezing capacity test, which is not very relevant), which is one of the regular in use factors shown to have a significant baring on cold appliance energy consumption.

Prospects for a conversion algorithm

In summary, the current refrigerator and freezer test procedures have varying levels of reproducibility and repeatability but are not likely to be very accurate at reflecting actual average in-use performance, even within a single economy's borders. To be able to achieve this would require a much more extensive characterisation of the system under a broad range of operating conditions coupled with an algorithm that is primed using data of actual local usage practice and conditions.

If enough details are known about a refrigerator or freezer it is possible to simulate its performance under any given set of operating conditions using the appropriate model, although there are considerable complications in simulating energy performance to a high degree of accuracy when there are complex combinations of convective, radiative and conductive heat transfer that are sometimes sensitive to subtle design and operational differences. Developing such a model is a serious task and it is by no means certain that is feasible, at least to the level of accuracy required for energy efficiency regulation and related programs. A number of refrigerator models are currently in existence, but their accuracy is either not very high (ERA model) or somewhat unclear at this stage. Work undertaken in recent years such as in the USA (Vineyard 1998) and at the *Ecole de Mines* in Paris may potentially form the basis for a suitable model. However, this research has generally been undertaken primarily for energy policy work, rather than as a test procedure so there is some question regarding its suitability. There is no clear process on how physical testing of refrigerators and computer simulation can be combined to increase the accuracy of results over a range of conditions, given the range of operating parameters, temperature ranges and loading conditions that are typical under the most common test procedures (not to mention real use).

Assuming that a sophisticated conversion algorithm (or computer model) combined with physical testing was feasible and suitably accurate, it would enable the magnitude of differences in the rated performance resulting from the differences in existing local test procedures to be quantified and for the impact of differences in individual parameters to be evaluated. This is likely to aid informed debate about test procedure alignment issues (as controversial as they may be) and the consequences of modifying any particular parameter. The computer modelling approach would also enable the impact of trade-offs caused by desirable simplifications of the test procedure against system characterisation accuracy to be quantified, that would substantially aid the discussions on how best to optimise development of the international test procedures.

In the case of refrigerators and freezers, the existence over many years of different interior design temperatures is likely to considerably complicate any efforts to align test procedures, as whole generations of products have been developed to perform optimally according to the local test requirements (as opposed to actual use). This means that changes in the test procedure would be likely to favour one tradition over another and hence be contentious; nonetheless the use of a computer model could quantify the likely impact and hence help guide an equitable transition to an aligned procedure should that be deemed desirable.

A computer model would also be capable of simulating actual use under a range of climate and temperature conditions and hence be much better placed to provide accurate and relevant advice to consumers (and even on energy labels) regarding the energy consumption of products. A computer simulation model would also assist in undertaking international comparisons of product performance and energy efficiency.

It is also certain that the efficiency ranking order of some products tested under standardised test conditions will be different to what a consumer experiences in actual use. So there is some potential (although probably not large at this stage) for consumers to be provided with inaccurate information under regulatory programs such as energy labelling. A computer simulation model has a much better probability of ranking models in their correct efficiency order when actual conditions of use are simulated.

In summary, for refrigerators and freezers, the way forward, at least in the short term, is unclear and most likely difficult. The differences in test procedures are so great and the number of economies involved is so large, that the prospects of alignment are small. In any case, all of the existing test procedures have strong and weak points in certain areas and there is no approach that is clearly superior to any other. There is also a huge amount of institutional (government and regulatory) and industrial inertia associated with existing test procedures for refrigerators in many economies, this also makes the prospects for changes somewhat dim.

Ultimately, a conversion algorithm (most likely a rather complex computer model with extensive calibration through physical tests) is the only medium term prospect to avoid (at least in part) the myriad of test methods that currently exist. However this is a complex and significant task and would require substantial resources merely to establish feasibility, let alone get it to an acceptable level of performance for regulatory purposes.

Recommendations for Refrigerators

Alignment in the short term appears to be very unlikely for refrigerators. Further investigations should be undertaken into both simple and more complex computer modelling options for refrigerators to determine their feasibility as algorithms for use with refrigerator test procedures. More extensive use of a test procedure with dual energy temperature test points and controlled internal heat loads may provide some insight and data to assist with modelling and algorithm approaches. Options investigated at the symposium showed that a separate temperature energy-performance function together with a separate heat load performance function and a humidity/defrost performance function may provide the building blocks required to develop a more flexible and relevant test procedure for refrigerators for all economies.

Options for Further Convergence

It is accepted that the objective of fully harmonised MEPS and energy labelling requirements for refrigerators and freezers throughout APEC is not practical nor necessarily appropriate, and in any case the costs and benefits of this approach for each APEC economy would need to be demonstrated.

However, the following options for further convergence are likely to bring significant benefits to all APEC economies. However, both of these options are difficult and may have substantial costs associated with them. The symposium also recommended useful options to be further investigated and developed.

1. Full harmonisation of test elements

In this scenario, there would be agreement to develop ISO international standards for the measurement of refrigerator and freezer so that there is a common and uniform basis for the determination of energy consumption, volume and performance. This could then be utilised by all APEC member economies to define MEPS and labelling requirements. This would require agreement on all elements of the test procedure such as test conditions, equipment accuracy and methodology for a range of technology types. However, given the existing major technical problems with the ISO standard (particularly for frost free models) and the already substantial resistance to its use in some regions, this option is unlikely to be adopted by all economies.

2. Development of a complex algorithm for refrigerators

In this scenario, a conversion algorithm (probably in the form of a set of physical test with a computer model) would be developed, with the aim of being able to accurately convert energy consumption values between existing test procedures. This approach would require a detailed physical description of the refrigerator (dimensions, performance attributes) together with some physical tests under controlled conditions to calibrate the computer model with the physical unit when under test. Such a model could easily be extended to model energy under a range of realistic usage conditions. Simulation of door opening could also be included via the inclusion of calibrated internal heat loads and defrost performance via the controlled introduction of humidity.

The problem is that such a model does not already exist and it is not clear that it is feasible. Even if feasible, it is likely to be expensive to develop and it would be some years before it would be available. It is also unclear whether regulators would accept such results in lieu of physical tests for mandatory programs such as energy labelling and MEPS - they are certain not to accept such an option until it is well established and well proven.

Although an attractive option in some respects, there are many uncertainties associated with it.

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Appendix 1: Summary of refrigerator and freezer test procedures

The source for this Appendix is EES 1999.

Key to Standard Prefixes

AHAM – Association of Home Appliance Manufacturers (USA)

ANSI – American National Standards Institute

AS – Australian Standards

CAN/CSA – Canadian Standards Association

CNS – Chinese National Standards of Chinese Taipei

GB – China State Bureau of Quality and Technical Supervision

GOST – Russian Committee for Standardisation

ISO – International Standards Organisation

JIS – Japanese Industrial Standards

KS – Korean Standards

MS – Malaysian Standards

NOM – Official Mexican Norms (CONAE)

NZS – New Zealand Standards

PNS – Philippine National Standards

TIS – Thai Industrial Standards

Summary

Test procedures currently in use in APEC Economies for the determination of refrigerator and freezer energy consumption and energy efficiency appear to basically fall into one of five broad categories:

1. ISO methods: a number of APEC economies either use ISO standards directly or have produced local standards that are based on ISO standards (China, Hong Kong; China, Indonesia, Peru, Philippines, Russia, Singapore, Thailand). However, many local versions of these test methods have been modified so that they are not equivalent to the source ISO standards. It is believed that there are also a mixture of climate requirements in use within APEC: temperate climate (energy consumption test undertaken at 25°C) and tropical climate (energy consumption test undertaken at 32°C), effectively meaning that there are two versions of ISO in use. Key elements of the test are: single ambient temperature (for each climate) with no door openings but freezer test packages always used for energy test, freezing capacity test, freezer temperature rise test, temperature operation test, anti-sweat heaters operated as required.

2. AS/NZS: This is used in Australia, New Zealand and throughout the Pacific region. The energy test method is similar in principle to the North American test method (energy consumption test undertaken at 32^{o}C), except that test packages are not used in freezers during the energy consumption test for all types of units. Temperature operation test is based on ISO but over a wider temperature range (10^{o}C to 43^{o}C). Pull down test is derived from AHAM. Key elements of the test are: single ambient temperature with no door openings and no freezer test packages used for energy test, temperature operation test, pull down test, anti-sweat heaters always on.

3. DOE/AHAM - North American test methods: This is used by USA, Canada and Mexico and has an energy consumption test undertaken at 32.2^{o}C (90^{o}F). Test packages are made of sawdust or spinach (which are different to ISO test packs). In the USA DOE CFR430 sets out most of the requirements and there are minimal external references to AHAM HRF-1-1979. Key elements of the test are: single ambient temperature with no door openings used for energy test, test packages are not used for frost free refrigerator-freezers but they are used in non-frost free models and all separate freezers, anti-sweat heaters average of on and off.

4. JIS - Japan: The JIS standard has undergone three changes in recent years so care needs to be taken to check which method was used. The Method A had door openings (without test packages) and two ambient temperatures for energy (15^{o}C and 30^{o}C). Method B, which was used briefly during the late 1990's, is essentially equivalent to ISO. Method C, which has been developed for the implementation of Top Runner, has an unloaded freezer compartment for forced air (loaded for natural convection models) and has door openings for both compartments but at half the frequency of Method A. Energy is measured at a single ambient temperatures (25^{o}C). Key elements of the test are: single ambient temperature with door openings and test packages sometimes used for the energy test, temperature operation test, pull down test, freezing capacity test, anti-sweat heaters always on.

5. KS/CNS - Korea and Chinese Taipei: Both of these test methods have been derived from the early JIS method and share many similarities with JIS, but energy consumption tests undertaken at a single ambient (30^{o}C) ***without*** door openings, so they differ substantially in this respect. The KS and CNS test methods appear to be largely identical to each other for all key aspects. Key elements of the test are: single ambient temperature with no door openings for energy test, no test packages for the energy test, temperature operation test, pull down test, freezing capacity test, anti-sweat heaters always on.

Key technical aspects of the five basic methods are summarised in the Tables below. The are a number of subtle differences between these tests, such as determination of compartment temperatures, instrumentation, setup, definition of equilibrium conditions and operation during the test which will also contribute to differences in test results. EES (1999) Annex A should be consulted for a detailed comparison of all of the APEC economy test procedure requirements for refrigerators and freezers.

Table 5: General refrigerator requirements for various test procedures

Compartment	Requirement	AS/NZS	ISO	DOE/AHAM [a]	JIS C	CNS/KS
All-Refrigerators	Ambient	32 ± 0.5°C	25/32 ± 0.5°C	32.2 ± 0.6°C	25 ± 1°C [b]	30 ± 1°C
	Fresh food	3 ± 0.5°C	5°C	3.3°C	3 ± 0.5°C	3 ± 0.5°C
Refrigerator-Freezers	Ambient	32 ± 0.5°C	25/32 ± 0.5°C	32.2 ± 0.6°C	25 ± 1°C	–
	Fresh food	3 ± 0.5°C	5°C	7.2°C	3 ± 0.5°C	3 ± 0.5°C
	Freezer *	–9 ± 0.5°C	–6°C	–9.4°C	–6 ± 0.5°C	–
	Freezer **	–15 ± 0.5°C	–12°C	–15°C	–12 ± 0.5°C	–12/–15 ± 0.5°C
	Freezer ***	–	–18°C	–	–18 ± 0.5°C	–18 ± 0.5°C
Separate Freezers	Ambient	32 ± 0.5°C	25/32 ± 0.5°C	32.2 ± 0.6°C	25 ± 1°C	30 ± 1°C
	Fresh food	–	–	–	–	–
	Freezer	15 ± 0.5°C	–18°C	–17.8°C	–18 ± 0.5°C	–18 ± 0.5°C
Freezer compartment	Energy test packages	Unloaded	Loaded	Sometimes [c]	Sometimes [c]	Unloaded
All	Door openings	No	No	No [d]	Yes	No
All	Operation test ambient	10/32/43°C	16/32°C [e]	21.1/32.2/43.3°C [f]	15/30°C	15/30°C
All	Pull down	Yes	No	Yes [f]	Yes	Yes
Freezer compartment	Freezing capacity	No	Yes	No	Yes	Yes
Freezer compartment	Temperature rise time	No	Yes	No	Yes	No
All	Anti-sweat heaters	Always on	When needed	Average on & off	Always on	Always on
All	Volume for labels/MEPS	Gross	Storage (for EU)	Storage	Storage	Storage

All temperatures are in °C.

[a] Mexico and Canadian requirements are equivalent to US DOE/AHAM

[b] Method C, Method A was 73% of the energy weighted at an ambient of 15°C and 27% at 30°C.
[c] Freezer compartments which are frost free (forced air) are generally unloaded. In USA, separate freezers are loaded irrespective of defrost type.
[d] In the case of adaptive defrost models, the manufacturer can elect to undertake a door opening test to determine mean time between defrosts if default parameters in the CFR are not used.
[e] This is the temperature range for ISO Temperate, which is the most common climate rating in Europe. Other ISO climate ratings include Extended Temperate (10°C/32°C), Sub-tropical (18°C/38°C) and Tropical (18°C/43°C).
[f] Part of the AHAM standard but is not required for DOE energy tests.

Table 6: Energy consumption test requirements for household refrigerators

	AS/NZS	ISO	ANSI/AHAM	JIS (method A)	CNS/KS
Installation of the refrigerator	Such that any shielding on either side of the cabinet is 300 ± 10 mm	On a wooden platform	Such that the distance from the wall is ≥254 mm	–	See manual[12]
Stable operating conditions	$\Delta T_{FF} \leq 0.5$°C/6 h $\Delta T_{FR} \leq 0.5$°C/6 h Over more than two cycles	$\Delta T_{FF} \leq 0.5$°C/24 h $\Delta T_{FR} \leq 0.5$°C/24 h	$\Delta T_{FF} \leq 0.023$°C/h $\Delta T_{FR} \leq 0.023$°C/h		$\Delta T_{FF} \leq 1$°C/24 h $\Delta T_{FR} \leq 1.25$°C/24 h
Humidity	Needs not to be controlled	45–75%	Needs not to be controlled	75 ± 5%	75 ± 5%
Ambient temperature					
Max vertical temp gradient	1°C/m from floor to 2 m height	2°C/m from platform to 2 m height	0.9°C/m from 51 mm above the floor	3°C from 50 mm above the floor	3°C from 50 mm above the floor to 2 m height
No of M points	1	3	2	1	1
Location of M points	250–350 mm from the front mid-height position	350 mm from the side/front walls	915 mm above the floor and 254 mm from the centre of the two sides	Either side of refrigerator to get a mean value	See manual[12]
Calculation	$T_A = T(T_{A1})^a$	$T_A = T(T_{A1}, T_{A2}, T_{A3})^a$	$T_A = T(T_{A1}, T_{A2})^a$	$T_A = ½(T_{Amax} + T_{Amin})$	$T_A = ½(T_{Amax} + T_{Amin})$
Fresh-food compartment					
No. Of M points	3	3	3	3	1
Compartment temperature	$T_{FF} = T(T_{FF1}, T_{FF2}, T_{FF3})$ i.e. mean of the average of all measured temperatures at that point	$T_{FF} = T(T_{FF1}, T_{FF2}, T_{FF3})$ with $T_{FFi} = ½(T_{FFimax} + T_{FFimin})$ where i = 1, 2, 3	$T_{FF} = T(T_{FF1}, T_{FF2}, T_{FF3})$	$T_{FF} = T(T_{FF1}, T_{FF2}, T_{FF3})$ with $T_{FFi} = ½(T_{FFimax} + T_{FFimin})$ where i = 1, 2, 3	$T_{FF} = ½T(T_{Ffmax} + T_{Amin})$ i.e. mean of the highest and the lowest recorded temperature
Freezer compartment					
Test load	No	Yes (100%)	Yes (75%); no load in automatic defrost models	No	No

Table 6: Energy consumption test requirements for household refrigerators (continued)

	AS/NZS	ISO	ANSI/AHAM	JIS (method A)	CNS/KS
No. Of M points	5	4–6	3–12	1	1
Size of M packs	–	50 × 100 × 100 mm	40 × 100 × 130 mm	–	–
Compartment temperature	$T_{FR} = T(T_{FRi})$, where i = 1–5 without the coldest sensor, i.e. mean of all recorded temperatures	$T_{FR} = T_{FRmax}$, i.e. maximum temperature of the warmest M package	$T_{FR} = T(T_{FRi})$, mean of all the recorded temperatures	$T_{FR} = ½(T_{FRmax} + T_{FRmin})$, i.e. mean of the highest and the lowest measured values	$T_{FR} = ½(T_{FRmax} + T_{FRmin})$, mean of the highest and the lowest measured values
Auto defrost operates.	Yes	Yes	Yes (manual defrost also)	Yes (not manual defrost)	Yes (not man. defrost)
Door openings	–	–	–	During first 10 h of test: a) FF every 12 min for 10 seconds b) FR every 40 min for 10 seconds **	–
Temperature readings	At least every 30 min for at least every 3 h		At least every 4 min		
Test period					
General	≥16 h but only until 1 kWh of energy is consumed	≥24 h	≥3 h and ≤24 h, so that compressor completes two or more whole cycles	= 24 h 1	= 24 h
With automatic defrost	From a point in one defrost cycle to a corresponding point in another cycle	Complete defrost cycles (if no defrost cycle starts during 24 h, the test period shall be 48 h)	From one point during a defrost period to the same point during the next defrost period	a) If defrosting once a day, start after 14 h after commencement of the test b) Others shall start > 5 h	a) If defrosting once a day, shall start > 14 h after commence the test b) Others to start > 5 h
Without automatic defrost	Between two compressor switch-off cycles	Whole number of control cycles	Whole number of control cycles		

[a] Mean of the average of all recorded temperatures. ** Freezer door shall not be opened when it is inside the cabinet

Appendix 2: Summary of refrigerator and freezer energy labelling and MEPS requirements by APEC Economy

The source for this Appendix is EES 1999.

Australia

Program regulation and coverage

The regulations cover refrigerators, freezers and refrigerator-freezers which are intended for household or similar use and which:

- operate using the vapour compression cycle; and
- use mains electricity (230/240 Volts at 50 Hz) as the primary power source.

There are 9 specific groups of product, described in Table 7.

Table 7: Refrigerator and freezer groups, energy labelling and MEPS, Australia

Type	Group	Frozen food compartment temp (°C)(a)	Description
Refrigerator	1	Nil	Refrigerator without a low temperature compartment, automatic defrost (all refrigerator).
	2	≤–2°C	Refrigerator with or without an icemaking compartment, manual defrost
	3	≤–9°C	Refrigerator with a short or long term frozen food compartment, manual defrost
Refrigerator-freezer	4	≤–15°C	Refrigerator-freezer, fresh food compartment is automatic defrost, freezer manual defrost ("partial automatic defrost")
	5	≤–15°C	Refrigerator-freezer, both compartments automatic defrost (frost free), top or bottom mounted freezer
	5S	≤–15°C	Refrigerator-freezer, both compartments automatic defrost (frost free), side by side configuration (b)
Freezer	6C	≤–15°C	Separate chest freezer, all defrost types
	6U	≤–15°C	Separate vertical freezer, manual defrost
	7	≤–15°C	Separate vertical freezer, automatic defrost (frost free)

Source: AS/NZS 4474.1-1997 (a) Standard condition for energy test; the fresh food compartment test temperature is 3°C for Groups 1 to 5S.
(b) Groups 5 & 5S can have natural convection fresh food cooling but must be all automatic defrost

Criteria and requirements

Refrigerators and freezers have to meet three groups of requirements before they can be legally sold.

- The product must pass a “Pull Down Test” and a “Temperature Operation Test” (although the energy consumption during those tests is not measured);
- An energy label indicating the comparative energy consumption (CEC) at a standard test condition for one year and the star rating must be registered for the product; and
- The CEC (comparative energy consumption on the label) at the standard test condition must be no greater than the value determined by the MEPS formula corresponding to the product category (from October 1999).

The star rating for the energy label is determined in the following steps:

- Identify the product group (see Table 7);
- Calculate the Adjusted Volume (AV, litres) = Fresh food volume + (K x frozen food volume); the values of K for each product category are in Table 8;
- Determine the annual Comparative Energy Consumption in kWh/year (based on energy per 24 hours obtained during test - based on average of 3 units)

The Energy Efficiency Rating and star rating are determined by the following equation;

$$EER = 23/3 - [\ 2 \times 1000 \times CEC\ ] / [\ 3 \times 365 \times V_{adj}\ ]$$

Note: New rating formulae are to come into force during 2000 - this will be in AS/NZS4474.2-2000

Table 8: Adjustment volume factors for refrigerators, Australia

Group	K
1	0
2	1.2
3	1.4
4	1.6
5	1.6
5S	1.6
6C	1.6
6U	1.6
7	1.6

Source: AS/NZS 4474.2-1997

From 1 October 1999, refrigerators, freezers and refrigerator-freezers manufactured in or imported into Australia must comply with a MEPS cut off level, determined as follows:

Maximum CEC (kWh/yr) under standard test conditioners

$$= Kf + (Kv \times V_{adj}) + Ad_{tot} + Awi \text{ (kWh/y)}$$

where:

Kf = Fixed allowance factor for that category (kWh/year)(Table 9);

Kv = Variable allowance factor for that category (kWh/year/L_{adj})(Table 9);

V_{adj} = Total adjusted volume (adjusted litres) (see previous formula);

Ad_{tot} = An allowance made where the number of external doors differs from the regular arrangement for that category (see AS/NZS 4474.2-1997 for details). The door allowance can be positive or negative.

Awi = An allowance of 120 kWh/y which applies where an appliance has a "through-the-door" ice dispenser.

Table 9: Factors in MEPS formulae for refrigerators and freezers, Australia

Category	Fixed allowance factor (Kf) kWh	Variable allowance factor (Kv) kWh/L_{adj}
1	368	0.892
2	300	0.728
3	330	0.800
4	424	1.020
5	424	1.256
5S	465	1.378
6C	248	0.670
6U	439	0.641
7	439	1.020

Source: AS/NZS 4474.2-1997: in effect from 1 October 1999

Testing standards and procedures

The energy consumption test and performances tests are in AS/NZS 4474.1-1997. These draw on both ISO and US AHAM tests.

In the Pull Down Test the unit is left off in an ambient temperature of 43^{o}C with the doors open, the doors are then closed and the unit is switched on. The unit must reach the internal compartment temperatures specified for its Group after a period of 6 hours (including any compressor trips). This test is based on the US AHAM HRF-1 pull down test.

In the Temperature Operation Test the unit must be able to maintain the internal compartment temperatures specified for its Category under external ambient temperatures of 10^{o}C, 32^{o}C and 43^{o}C. This test and the temperatures are identical to the ISO Temperature Operation Test, although these three test temperature conditions are more extreme than is required for any one ISO climate rating.

Energy consumption is then measured while the unit maintains the compartment target temperatures shown in Table 7 while operating at an ambient temperature of 32^{o}C. During the energy consumption test, the freezer compartment does not contain test packages and any automatic defrost mechanism is allowed to operate (same is US DOE procedure). Energy consumption is measured over a whole number of defrost cycles and there are separate procedures for adaptive defrost systems (where time between defrosts exceeds 24 hours). There are no door openings in the test procedure. All tests are undertaken with a power supply at 240 Volts and 50 Hz.

Canada

Program regulation and coverage

The Regulations cover household refrigerators or refrigerator-freezers with a capacity of not more than 1100 L (39 cu ft), and freezers with a capacity of not more than 850 L (30 cu ft). The product categories, shown in Table 10, are completely aligned with the US program (except that there are no "compact" product categories).

Table 10: Refrigerator and freezer categories, Canada

Product Class	Description	Maximum annual energy consumption (kWh/yr)
1	Refrigerators and refrigerator-freezers with manual defrost	13.5 AV + 299
2	Refrigerator-freezers with partial automatic defrost	10.4 AV + 398
3	Refrigerator-freezers with automatic defrost with top-mounted freezer, no through-the-door ice service; and all refrigerators with automatic defrost	16.0 AV + 355
4	Refrigerator-freezers with automatic defrost with side-mounted freezer, no through-the-door ice service	11.8 AV + 501
5	Refrigerator-freezers with automatic defrost with bottom-mounted freezer, no through-the-door ice service	16.5 AV + 367
6	Refrigerator-freezers with automatic defrost with top-mounted freezer, and with through-the-door ice service	17.6 AV + 391
7	Refrigerator-freezers with automatic defrost with side-mounted freezer, with through-the-door ice service	16.3 AV + 527
[8](a)	Upright freezers with manual defrost	10.3 AV + 264
[9](a)	Upright freezers with automatic defrost	14.9 AV + 391
[10](a)	Chest freezers and all other freezers	11.0 AV + 160

Source: NRCan (1999) AV=Adjusted volume in cubic feet. (a) Not given a product number in Canadian regulations; this is the corresponding class number in US regulations.

Criteria and requirements

The MEPS criteria, adopted in February 1995, are identical with those which became effective in the US in January 1993. It is not known whether or when Canada proposes to adopt the next round of US MEPS for these products, which are due to take effect in July 2001 in the USA. MEPS levels for each product class are defined in terms of adjusted volume.

AV (Adjusted volume, cu ft) = Volume of fresh food compartment (cu ft) + (K $\times$ volume of freezer compartment (cu ft)).

The values of K are:

- 1.0 for a refrigerator without a freezing compartment;

- 1.44 for a single-door refrigerator with an internal freezing compartment
- 1.63 for a combination refrigerator-freezers
- 1.73 for a freezer.

Testing standards and procedures

The test procedure is in CAN/CSA-C300-M91. It is essentially harmonised with US 10 CFR Part 430. The test is carried out at an ambient temperature is 32.3°C (90°F) with the doors closed and with the following target internal temperatures:

- 3.3°C (38°F) in the fresh food compartment of a refrigerator
- ≤ 7.22°C (45°F) in the fresh food compartment of a refrigerator-freezer;
- -9.4°C (15°F) in the freezer compartment for a refrigerator (Product Class 1);
- -15.0°C (5°F) in the freezer compartment for a refrigerator-freezer (Class 2 to 7);
- -17.8°C (0°F) for a separate freezer.

China

Regulation or program (effective date)

GB 12021.2-89: *The limited value and testing method of the energy consumption for household refrigerators* (1990)

Product category

All household refrigerators and refrigerator-freezers.

Criteria and requirements

New MEPS criteria are being considered by CSBTS but no release date is yet agreed. The currently applicable MEPS levels are defined in Table 11.

Table 11: MEPS requirements for refrigerators and refrigerator-freezers, China

Types	Volume (in litres)	The limited value of energy consumption (kWh)/24h
Refrigerators (N and ST climatic class)1, [2, 3, 4]	≤ 100	≤ 0.5
	100 –129	≤ 0.6
	130 –149	≤ 0.7
	150 – 179	≤ 0.8
	180 – 209	≤ 0.85
	210 – 250	≤ 0.95
Refrigerator-freezers and refrigerators with 3-star frozen food compartment (N, ST climatic class) [3, 4]	100 – 139	≤ 1.0
	140 – 159	≤ 1.1
	160 – 179	≤ 1.2
	180 – 209	≤ 1.3
	210 – 249	≤ 1.4
	250 – 299	≤ 1.5
	300 – 350	≤ 1.6

1 The limited value of energy consumption of refrigerators with a 1-star frozen food compartment is 0.03 kWh/24h more than that for refrigerators with the same volume.
2 The limited value of energy consumption of refrigerators with a 2-star frozen food compartment is 0.10 kWh/24h more than that for refrigerators with the same volume.
3 If the volume of the frozen food compartment is more than 30% of the refrigerators volume the limited value of energy consumption is 0.10 kWh/24h more than that for refrigerators with the same volume.
4 The limited value of energy consumption of household frost-free refrigerators is 15% more than indicated in the table for those appliances with the same volume.

Refrigerators and refrigerator-freezers rated as belonging to the SN or T climatic class are not subject to the MEPS regulations, neither are pure freezers or cold appliances outside the specified volume ranges.

Testing standards and procedures

China's refrigerator and freezer test procedures are equivalent clones of the international test procedures as follows:

- GB/T8059.1 EQV ISO 7371-95: *Household refrigerating appliances – refrigerators with or without low-temperature compartments – characteristics and test methods*
- GB/T8059.2 EQV ISO 8187-91: *Household refrigerating appliances - refrigerator-freezers – characteristics and test methods*
- GB/T8059.1 EQV ISO 5155-95: *Household refrigerating appliances - frozen food storage cabinets and food freezers – characteristics and test methods*
- GB/T8059.1 EQV ISO 8561-95: *Household frost-free refrigerating appliances - Refrigerators, refrigerator-freezers, frozen food storage cabinets and food*

freezers cooled by internal forced air circulation – characteristics and test methods

Japan

Regulation or program (effective date)

Law Concerning the Rational Use of Energy – *Effectively Mandatory* Minimum Efficiency Standards (1979), revised to include Top Runner requirements in 1999.

Product category

All household refrigerators and refrigerator-freezers

Criteria and requirements

New criteria and energy efficiency standard levels were announced by MITI under the Top Runner program during 1999 to come into force in 2004.

Top Runner refrigerator and freezer requirements are as follows:

Refrigerator with free air circulation E = 0.427V +178
Refrigerator with forced air circulation E = 0.427V+178

Refrigerator-freezer with free air circulation E = 0.433V + 320
Refrigerator-freezer with forced air circulation and special feature E = 0.507V + 147
Refrigerator-freezer with forced air circulation with no special feature E=0.433V+340

Freezer with free air circulation E = 0.281V + 353
Freezer with forced air circulation E = 0.281V + 353

Where:

E = maximum allowable energy in kWh/year

V = internal compensated volume in litres (also called adjusted volume) - volume adjustment factors as the same as Europe and determined from $(T_a - T_c)/(T_a - 5)$ where T_a is the ambient test temperature of 25^oC and T_c is the compartment temperature (eg freezer = -18^oC therefore freezer compensation (adjustment) factor = 2.15)

Special features are nominated in the regulations and include vacuum insulation panels and variable speed drive compressors. Free air is also know as natural convection and forced air is also known as frost free.

Testing standards and procedures

Japan uses its own national testing procedure JIS C9607-1993: Household Electric Refrigerators, Refrigerator-Freezers, and Freezers, which also references ISO 8561-1995: Refrigerators, refrigerator-freezers, frozen food storage cooled by internal forced air circulation. Note that there have been 3 versions of the JIS standard for refrigerators in recent years. The version used for Top Runner is method C developed in 1998 and includes door openings.

Korea

Program regulation and coverage

The MEPS and labelling requirements cover household refrigerators and refrigerator-freezers of all capacities.

Criteria and requirements

Table 12 indicates the present MEPS levels (expressed as maximum energy consumption) for the three different product categories. Table 13 relates the rating scale used in energy labelling to the "target" values in Table 12. All of these values are currently being reviewed.

Table 12: MEPS and targets for refrigerators and refrigerator-freezers, Korea

Type	Maximum Energy Consumption (kWh/month)(a)	Target Energy Consumption (kWh/month)(b)
Refrigerator, all sizes	0.041AV+20.82	0.033AV+16.86
Refrigerator-freezer, <500 litres AV	0.042AV+37.79	0.032AV+28.79
Refrigerator-freezer, ≥500 litres AV	0.145AV-14.15	0.110AV-10.74

Source: KIER (1997) Effective date I January 1996. (a) As of I January 1997 (b) By the end of 1998

AV (Adjusted volume, litres) = Refrigerator volume + (K × freezer volume).

$K = (T_1-T_3)/(T_1-T_2)$ where:

T_1 = ambient temperature (30°C);
T_2 = average refrigerator temperature (3°C);
T_3 = average freezer temperature.

K = 1.56 for 2 star freezers (where T_3 = -12°C), K = 1.67 for super 2 star freezers (where T_3 = -12°C). K= 1.78 for 3 and 4 star freezers (where T_3 = -18°C).

Table 13: Ratings for refrigerators and freezers, Korea

R	Grade
R ≤ 1.00	1
1.00 < R ≤ 1.20	2
1.20 < R ≤ 1.40	3
1.40 < R ≤ 1.50	4
1.50 < R	5

Testing standards and procedures

The energy consumption test, described in KS C 9305-1996, is a closed-door test at an ambient temperature of 30°C. For the test the freezers are loaded with packages containing approximately 23% cellulose (these are the same as ISO test packs), except for those models that have forced air (frost free) freezer compartments (now the majority of models in Korea).

Mexico

Mexican residential refrigerators MEPS are currently specified by NOM-015-ENER-1997 in effect since 1 August 1997. This NOM substituted the previous NOM-071-SCFI-1994 that had been in effect since 1 January 1995.

The current standard is basically identical to USDOE 1993 MEPS for residential refrigerator/freezers. Tests are even conducted at 115 Volts (instead of the 127 Volts as previously stipulated). The test method is the same as CAN/CSA C300-M89 and US DOE CFR430 Subpart B Appendix A and B.

The NOM-015-ENER establishes MEPS limits for maximum yearly energy consumption as shown in Table 14. These limits are identical to those of USDOE 93.

Table 14. MEPS levels for refrigerators, Mexico

	Description of Electric Refrigerators	Maximum energy
1	Refrigerators &Refrigerator–freezers by manual/semiauto defrost	0.476 VA + 299
2	Refrigerator – Freezers - partial automatic defrost	0.367 VA + 398
3	Refrigerator – Freezers - automatic defrost with top-mounted freezer without through-the-door ice service and all-refrigerators-automatic defrost.	0.564 VA + 355
4	Refrigerator – Freezers – automatic defrost with side-mounted freezer without through-the-door ice service.	0.416 VA + 501
5	Refrigerator – Freezers – automatic defrost with bottom-mounted freezer without through-the-door ice service.	0.582 VA + 367
6	Refrigerator – Freezers – automatic defrost with top-mounted freezer with through-the-door ice service.	0.620 VA + 391
7	Refrigerator – Freezers – automatic defrost with side-mounted freezer with through-the-door ice service.	0.575 VA + 527
8	Upright Freezers with manual defrost.	0.364 VA + 264
9	Upright Freezers with automatic defrost.	0.526 VA + 391
10	Chest Freezers with manual defrost.	0.388 VA + 160

Maximum energy consumption in kWh/year; VA = Adjusted volume in litres, Source: NOM-015-ENER-1997. MEPS levels above are identical to US DOE 1993 (see CFR430 Subpart C 430.32)

NOM-015-ENER also requires that all residential refrigerators and freezers have the official yellow energy label for that product attached at the point of sale. The refrigerator label shows brand. Model, energy consumption and the energy savings of the actual energy consumption of that model relative to the MEPS for that model.

New Zealand

The labelling of refrigerators and freezers with the Australian comparative energy labels occurs on a voluntary basis in New Zealand. Product coverage, labelling criteria and requirements, test standards and procedures are therefore all identical to those detailed in the section on Australia. In the event that New Zealand should decide to adopt MEPS for refrigerators and freezers, it is highly likely that the requirements will also be identical to those in Australia.

Philippines

Regulation or program (effective date)

Labelling for refrigerators (introduced late 1999).

Product category

Refrigerator/freezers.

Criteria and requirements

Label must display energy efficiency factor (EEF), power input, and volume (litres). Calculation of EEF not determined.

Testing standards and procedures

FATL uses the Philippine National Standard PNS 1474:1997, PNS 1475:1997, PNS 1476:1997, and PNS 1477:1997, which respectively:

- ISO 5155-1995: Frozen food storage cabinet and food freezer
- ISO 7371-1995: Refrigerators with or without low-temperature compartment
- ISO 8187-1991: Refrigerator-freezer
- ISO 8561-1995: Refrigerators, refrigerator-freezers, frozen food storage cooled by internal forced air circulation

Other standards which are relevant for refrigerators in the Philippines are:

- PNS 185:1989: Method for Determining the Energy Consumption, Freezer Temperature and Energy Efficiency Factor of Refrigerators and Freezers for Household Use (no longer in use)
- PNS 165:1998: Method of Computing Total Refrigerated Volume and Total Shelf Area of Refrigerators and Freezers for Household Use

Russia

Regulation or program (effective date)

GOST 16317-87: Electric domestic refrigerating appliances. General specifications (1991).

Product category

Household refrigerators, refrigerator-freezers and freezers (including both vapour compression and absorption types).

Criteria and requirements

The MEPS levels, that have been applicable since 1991, are defined in Table 15.

Table 15: Refrigerator and freezer MEPS, Russia

Volume (litres)	Fridge no FFC	Fridge with 2-star FFC	Fridge with 3-star FFC	Fridge with 3-star FFC with 2 doors	Fridge with 3-star FFC with 3 doors	Fridge with 3-star FFC	Refrigerator-freezers	Freezers	Fridge with 1-star FFC	Fridge with 2-star FFC	Fridge with 3-star FFC	Fridge with 3-star FFC and 2 doors
	Vapour-compression models							Absorption models				
	Daily electricity consumption (kWh/day)											
80								0.864	1	1.25	1.5	
120		0.624	0.749					0.996	1.08	1.35	1.62	
140	0.588	0.686	0.823						1.05	1.3125	1.575	
160								1.136				
180	0.684	0.774	0.929									
200		0.780	0.936					1.2				1.56
220	0.704	0.770	0.924					1.254	1.1	1.375	1.65	1.65
240		0.792	0.950									
250				0.900								
260		0.832	0.998									1.69
270				0.918								
280		0.840	1.008	1.02								
300		0.840	1.008	1.12	1.02	1.05						
350					1.05	1.12						
400				1.2	1.2	1.28						
420						1.344						
450					1.26	1.44						

Testing standards and procedures

Russia's refrigerator and freezer test procedures are based on, but are not identical to, ISO international test procedures. The test procedure is given in the MEPS regulations:

GOST 16317-87: Electric domestic refrigerators. General specifications (1991)

This procedure references the international procedures:

ISO 7371-85: Household refrigerating appliances – refrigerators with or without low-temperature compartments – characteristics and test methods

ISO 5155-83: Household refrigerating appliances - frozen food storage cabinets and food freezers – characteristics and test methods

ISO 3055: Kitchen equipment - Coordinating sizes.

Singapore

Regulation or program (effective date)

Singapore Green Labelling Scheme (1998).

Product category

Residential household refrigerators and/or refrigerator-freezers

Criteria and requirements

The product is awarded the Green Label if the refrigerator/freezer meets both the following criteria:

- Product shall not contain cholorofluorocarbons (CFCs).
- The energy consumption shall not be higher than 0.72 kWh per 100 litres of equivalent capacity in 24 hours.

The "equivalent capacity" is defined as follows:

Equivalent capacity = Vr + 1.85·Vf
Vf = volume of freezer compartment
Vr = volume of all other compartments
Correction factor = [32^{o}C - (-18^{o}C)]/[32^{o}C - 5^{o}C] = 1.85

Testing standards and procedures

The Electrical & Electronics Test Centre conducts energy performance testing according to:

- ISO 8187: Refrigerator-freezer
- ISO 8561: Refrigerators, refrigerator-freezers, frozen food storage cooled by internal forced air circulation

There is also Scheme for 1-year Accelerated Depreciation Tax Incentive (1996) for all commercial and industrial refrigeration systems (refrigerators, refrigerator-freezers, and separate freezers). No testing is required but estimated energy savings are to be certified by a qualified engineer.

Chinese Taipei

Program regulation and coverage

The reference for the MEPS levels is File (85) of energy 84462391 issued by MOEA on 3 January, 1996. The scope covers refrigerators and two types of refrigerator-freezer: "direct cooling" (assumed to be fan forced) and "indirect cooling" (convection).

The test standard covers which covers refrigerators and refrigerator-freezers with net refrigerated volumes of 700 L or less and vertical freezers of 400 L or less, so it is assumed that this defines the scope for MEPS as well.

Criteria and requirements

Table 16 summarises the MEPS levels for three different product classes, expressed as minimum Energy Factors. The steps in determining whether a product meets the MEPS level are:

1. carry out the power consumption test
2. calculate the unit's Energy Factor (litres equivalent internal volume per kWh/month)
3. calculate the Minimum Energy Factor using Table 16.
4. if the unit's Energy Factor is greater than the Minimum, the unit meets MEPS.

Table 16. Energy factors for refrigerators and refrigerator-freezers, Chinese Taipei

Type	Minimum Energy Factor (L/kWh/month)
Indirect cooling refrigerator-freezer	$EF = V/(0.067V+44.0)$
Direct cooling refrigerator-freezer	$EF = V/(0.058V+34.0)$
Refrigerator	$EF = V/(0.058V+27.2)$

Source: MOEA (1999)

Equivalent internal volume V = VR + K × VF, where:

VR is actual internal volume of refrigerator chamber (litres);
VF is actual internal volume of freezer chamber (litres).

$K = (T_1-T_3)/(T_1-T_2)$ where:

T_1 = ambient temperature (30°C);
T_2 = average refrigerator temperature (3°C);
T_3 = average freezer temperature.

K = 1.56 for 2 star freezers (where T_3 = -12°C), K = 1.67 for super 2 star freezers (where T_3 = -12°C). K= 1.78 for 3 and 4 star freezers (where T_3 = -18°C).

Testing standards and procedures

The energy tests are described in CNS 2062-95, which covers refrigerators and refrigerator-freezers with net refrigerated volumes of 700 L or less, and vertical freezers of 400 L or less. Four star freezers are tested with a test load of at least 4.5 kg per 100 L of effective volume for the freezing capacity test. Energy consumption is recorded over 24 hours once steady state temperature conditions are reached without test packages.

Greenmark Endorsement Label

The GreenMark logo label may be used on product packaging, brochures or on the products themselves itself if the performance of the product meets the stated criteria and the supplier registers with the Environmental Protection Administration (EPA) in

Chinese Taipei. Each product has a different set of criteria, covering matters as diverse as:

- absence of certain materials (eg CFCs or toxic substances) in the product itself;
- absence of the use of certain materials in the production process;
- the use of recycled materials in packaging;
- the disclosure of information, and the accuracy of disclosed information;
- noise levels in operation;
- functional requirements; and
- energy performance requirements.

To be eligible to use the GreenMark label, the following energy-related criteria need to be met for refrigerators and freezers: energy consumption must be 85% of the MEPS level for "fan-type" refrigerator-freezers, 90% or less of the MEPS level for "direct cooling" refrigerator-freezers, and 90% or less of the MEPS level for refrigerators.

Thailand

Regulation or program (effective date)

- EGAT's Energy-Efficient Refrigerator (*Voluntary* Labelling) Program (1994)
- EGAT's Energy-Efficient Refrigerator (*Mandatory* Labelling) Program (target 1999)
- Minimum Energy Performance Standards (MEPS) set by NEPO and DEDP (target 1999).

Product category

For labelling: Single-door, 5-6 ft^3 (140-170 litre), manual-defrost refrigerator, but program to be expanded to 2-door and larger sizes in 1999.

For MEPS: All household refrigerator-freezers, refrigerators, and freezers are being considered.

Criteria and requirements

To obtain an energy label, 1 sample unit must be randomly selected from a pool of at least 30 units of the same model (same size and features) and sent to TISI for energy performance testing. Once the model has been tested, it is issued a numbered ranking between 1 to 5. The manufacturer/distributor may choose whether or not to request the labels for their products.

Table 17 shows the average "efficiency values" of Thai CFC and non-CFC refrigerators of various sizes. An "efficiency value" is defined as the ratio of the capacity of the refrigerator (volume; in litres) to the amount of energy consumption (kWh) per day (24 hours); thus the units are litres/kWh. A higher efficiency value indicates a more efficient refrigerator.

Table 17: Average refrigerator efficiency values in Thailand

Capacity or Volume (litre)	CFC Refrigerator Average Efficiency Value (litres/kWh)	Non-CFC Refrigerator Average Efficiency Value (litres/kWh)
Size < 90	59.98	53.98
90 < Size < 120	208.82	187.94
120 < Size < 150	210.86	189.77
150 < Size < 180	213.92	192.53
180 < Size < 210	245.25	220.73
Size > 210	260.80	234.72

A tested refrigerator may receive a ranking number of 1, 2, 3, 4, or 5 (5 being the most efficient) depending on its efficiency value compared to the average efficiency value within one of the size categories.

Number 1: A refrigerator will receive a number 1 label if its efficiency value is *at least 30% less than* the average efficiency value.

Number 2: A refrigerator will receive a number 2 label if its efficiency value is *15 to 30% less than* the average efficiency value.

Number 3: A refrigerator will receive a number 3 label if its efficiency value is *between –15% and +10%* of the average efficiency value.

Number 4: A refrigerator will receive a number 4 label if its efficiency value is *10 to 25% greater than* the average efficiency value.

Number 5: A refrigerator will receive a number 5 label if its efficiency value is *at least 25% greater than* the average efficiency value.

NEPO has commissioned a study to make recommendations to the Thai government for MEPS. For MEPS, a product must exceed the minimum energy efficiency level to be eligible for sale in the market. The minimum efficiency level has not been determined but will most probably be based on the capacity of the refrigerator or on level 3, 4, or 5 of the EGAT label.

Testing standards and procedures

For the labelling program and future MEPS testing, TISI uses the Thai national standard TIS 455-2537 (1994): Standard for household refrigerators, which references ISO 7371-1995: Performance of household refrigerating appliances (Amendment 1-1987: Refrigerators with or without low temperature compartment). Testing is undertaken for tropical conditions (32^oC ambient).

USA

Program regulation and coverage

The MEPS regulations cover household refrigerators or refrigerator-freezers with a capacity of not more than 1100 L (39 cu ft), and freezers with a capacity of not more than 850 L (30 cu ft). Classes 1 to 10 in Table 18 were defined for the purposes of setting the first MEPS levels under the NAECA (which took effect on 1 January 1990) and those which took effect on January 1 1993, which still apply.

For the next round of MEPS, which take effect on 1 July 2001, where new classes of "compact" refrigerators and freezers have been defined. Compact refrigerators are those that are both less than 220 litres (7.75 cu ft) and less than 0.91 metres (36 inches) high.

Criteria and Requirements

MEPS levels for each product class are defined in terms of adjusted volume.

AV (Adjusted volume, cu ft) = Volume of fresh food compartment (cu ft) + (K × volume of freezer compartment (cu ft)).

The values of K are:

- 1.0 for a refrigerator without a freezing compartment;
- 1.44 for a single-door refrigerator with an internal freezing compartment
- 1.63 for a combination refrigerator-freezers
- 1.73 for a freezer.

The EPA's Energy Star label may be used on models is currently available to refrigerator-freezers of Classes 3 to 7 where tested energy consumption is 20% or more below the MEPS level that will take effect in 2001.

Testing standards and procedures

The test procedure is specified in CFR Part 430, Subpart B, Appendix A1. The test is carried out at an ambient temperature of 90°F (32.3°C) with the doors closed and with the following target internal temperatures:

- 38°F (3.3°C) in the fresh food compartment of a refrigerator or a refrigerator-freezer;
- 15°F (-9.4°C) in the freezer compartment for a refrigerator (Product Class 1);
- 5°F (-15.0°C) in the freezer compartment for a refrigerator-freezer (Class 2 to 7);
- 0°F (-17.8°C) for a separate freezer.

Table 18: Refrigerator and Freezer categories, USA

Product Class	Description	Maximum annual energy consumption (kWh/yr)	
		Effective January 1, 1993	Effective July 1, 2001
1	Refrigerators and refrigerator-freezers with manual defrost	13.5 AV + 299	8.82 AV + 248.4
2	Refrigerator-freezers with partial automatic defrost	10.4 AV + 398	8.82 AV + 248.4
3	Refrigerator-freezers with automatic defrost with top-mounted freezer, no through-the-door ice service; and all refrigerators with automatic defrost	16.0 AV + 355	9.8 AV + 276
4	Refrigerator-freezers with automatic defrost with side-mounted freezer, no through-the-door ice service	11.8 AV + 501	4.91 AV + 501
5	Refrigerator-freezers with automatic defrost with bottom-mounted freezer, no through-the-door ice service	16.5 AV + 367	4.6 AV + 459
6	Refrigerator-freezers with automatic defrost with top-mounted freezer, and with through-the-door ice service	17.6 AV + 391	10.2 AV + 356
7	Refrigerator-freezers with automatic defrost with side-mounted freezer, with through-the-door ice service	16.3 AV + 527	10.1 AV + 406
8 (a)	Upright freezers with manual defrost	10.3 AV + 264	7.55 AV + 258.3
9 (a)	Upright freezers with automatic defrost	14.9 AV + 391	12.43 AV+ 326.1
10 (a)	Chest freezers and all other (non-compact) freezers	11.0 AV + 160	9.88 AV + 143.7
11 (b)	Compact Refrigerators and Refrigerator-Freezers with Manual Defrost	13.5 AV+ 299	10.70 AV+ 299.0
12 (b)	Compact Refrigerator-Freezer—partial automatic defrost	10.4 AV + 398	7.00 AV+ 398.0
13 (b)	Compact Refrigerator-Freezers automatic defrost with top-mounted freezer and compact all-refrigerators - automatic defrost	16.0 AV + 355	12.70 AV+ 355.0
14 (b)	Compact Refrigerator-Freezers - automatic defrost with side-mounted freezer	11.8 AV + 501	7.60 AV+ 501.0
15 (b)	Compact Refrigerator-Freezers - automatic defrost with bottom-mounted freezer	16.5 AV + 367	13.10 AV+ 367.0
16 (b)	Compact upright freezers with manual defrost	10.3 AV + 264	9.78AV + 250.8
17 (b)	Compact upright freezers with automatic defrost	14.9 AV + 391	11.4 AV + 152
18 (b)	Compact chest freezers	11.0 AV + 160	10.45 AV + 152

Source: CFR430, Subpart C, Clause 430.32. AV = Adjusted volume in cubic feet. (a) Not given a product class in Canadian regulations, but covered under "Freezers" (b) Compact products not separately defined under current Canadian regulations.

Appendix C - Refrigerator Related Definitions

Some of the frequently used terms and definitions in this section that are relevant to the test standards (after Bansal and Kruger 1994 and from ISO standards).

Household refrigerator

A household refrigerator is defined as a cabinet or any part of a cabinet that is designed for the refrigerated storage of food at temperatures above 0 °C, has a source of refrigeration and is intended for household use. It may include a compartment for the freezing and storage of ice and/or for storage of food at temperatures below 0 °C (typically at –15 °C to –18 °C). Household refrigerators can be divided into two classes.

- *Refrigerator*
  An All-Refrigerator is a cabinet which does not include a compartment for the storage of food at temperatures below 0 °C. A refrigerator may include a compartment with a small volume for freezing and storage of ice or a short term frozen food compartment.
- *Refrigerator-Freezer*
  A Refrigerator-Freezer is a cabinet which consists of two or more compartments, with at least one of the compartments designed for the refrigerated storage of food at temperatures above 0 °C and with at least one of the compartments designed for the freezing and long term storage of frozen food.

Household freezer

A household freezer is defined as a separate cabinet which is designed for the extended storage of frozen food generally at an average temperature of –15 °C of below. It has a source of refrigeration and is intended for household use.

Fresh-food compartment

A fresh-food compartment is intended for the storage of unfrozen food at an average temperature above 0 °C, and may be subdivided into smaller zones or compartments allocated for the storage of particular types of product.

Freezer compartment

A compartment which is intended specifically for he freezing and/or storage of frozen food, and may include an ice-making zone or function. The classification of freezer compartments according to their storage temperatures is different in most of the test standards. Thus, to have a conformity among these standards, the freezer compartments are classified in this study by using the International Standards classification, as follows:

- 'One-Star' Compartment (*)
  Compartment in which the storage temperature is not warmer than –6 °C
- 'Two-Star' Compartment (**)
  Compartment in which the storage temperature is not warmer than –12 °C
- 'Three-Star' Compartment (***)
  Compartment in which the storage temperature is not warmer than –18 °C.

Control cycle

A control cycle is the period between two successive starts or two successive stops of the compressor of a refrigerating system. Note some models may have variable speed compressors which operate continuously.

Defrost cycle

A defrost cycle is the period between two successive starts or two successive stops of a defrost heater in a refrigerator-freezer having an automatic defrost system.

Test package

Most of the standards typically use test packages in food storage tests while the ISO requires loading of the freezer compartment with test packages for the energy consumption test. The packages are used to simulate food load in the freezer compartment, Their function is to provide thermal ballast and fill up the space. The chemical composition of the packages per 1000 g is:

- 764.2 g of water
- 230.0 g of oxyethylmethylcellulose
- 5.0 g of sodium chloride
- 0.8 g of parachlorométhacresol.

The freezing point of this material is –1 °C. The thermal characteristics of the packages correspond to those of lean beef.

Measurement package (‘M-package’)

A measurement package (also called an ‘M-package’) is a 500 g (50 mm × 100 mm × 100 mm) test package fitted with a temperature sensor (thermocouple) at its geometric centre which shall be in direct contact with the filling material.

M-points

‘M-points’ are the number of measurement points used to record the temperature of each M-pack.

Characteristic temperature

This is the temperature within the compartment of a cabinet that needs to be achieved during a test for the energy consumption measurement.