A New Global Test Procedure for Household Refrigerators

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Abstract

There is a significant amount of trade in household refrigerators around the world. World production of refrigerators was estimated to be 90 million units per annum in 2008. Refrigerators are an important energy consuming appliance in the residential sector, and to some extent in the commercial sector. Internationally, there are about 60 countries world wide that have some sort of program to regulate the energy efficiency of refrigerators[1] and separate freezers, mostly in the form of mandatory comparative energy labeling and minimum energy performance standards (MEPS).

Despite being a product that is widely traded internationally, refrigerators have poorly aligned test procedures. Most current test procedures determine the energy consumption at a single ambient temperature. Ironically, ambient temperature has the largest single impact on the energy consumption of a refrigerator. Another attribute which is not quantified in most current test procedures is processing load – this occurs from door openings and the cooling of food and drinks. Processing efficiency can vary by a factor of four across models.

The IEC took over the responsibility of household refrigeration with TC59 (household appliances) in 2006. This paper outlines the latest in the development of a new global test procedure for refrigerators which will quantify the key relationship between ambient temperature and energy consumption and should include the quantification of a load related (usage) factor which can be scaled up (or down) to reflect actual usage in different parts of the world. If achieved, this will facilitate the identification of, and trade in, highly efficient models and will ensure that energy labeling and MEPS systems correctly rank and regulate refrigerators on the basis of their actual energy consumption for typical use.

Market Overview for Refrigerators

By any benchmark, global production and trade in refrigerators is massive, hence the energy impacts are also large. Global production of refrigerators was estimated to be 73 million units per annum in 1992 [20] while production within APEC was estimated to be nearly 40 million units in that year, or nearly 60% of world production. Current world production of refrigerators is now estimated to be close to 90 million units per annum, with China now becoming increasingly important on the world manufacturing stage [3]. Production in Asia is currently about 45 million units a year (China accounts for more than 30 million units) while total pan-European production is around 25 million units and North and South America about 20 million units a year, with little production elsewhere. The prevalence of different configurations varies considerably by region, but at a global level, top freezers are the most common (nearly 40%), bottom freezers are next at about 33% and side by side are about 13%. The remaining types are mostly single door refrigerators or other configurations including separate freezers.

Refrigerators are an important energy consuming appliance in the residential sector and, to some extent, in the commercial sector. In developed countries, ownership rates are either stable or growing slowly, varying from 0.9 to 1.5 units per average household (plus additional separate freezers). In developing countries, ownership is highly varied but in most cases is rapidly increasing as living standards increase [18]. Given the relatively long life of refrigerators (up to 20 years in developed countries), the world stock could be well over 1 billion units in operation at the moment, although data on this statistic is scant. The IEA estimate that the stock of refrigerators in the OECD was over 500 million in 2000 [19].

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[1] Refrigerators include refrigerators and refrigerator-freezers. The term freezers refers to separate stand alone freezers. However, the term refrigerators in this paper generally means household refrigeration appliances, which includes all of these products.

Refrigerators are one of the few appliances that remain "on" continuously and as such consume a significant amount of electricity during normal use. Electricity consumption of refrigerators typically range from 100 to 1000 kWh or more per annum, depending on the design, size, features and efficiency. This constitutes a significant share of household electricity consumption in most countries. In Australia, household refrigerators account for about 12% of residential electricity consumption, or some 26 PJ per year (7.2 TWh/year) in 2008 [1].

Given that refrigerators are significant users of electricity, it is hardly surprising that they are the focus of attention of many programs that aim to reduce electricity consumption and greenhouse gas emissions associated with power generation. There are nearly 60 countries that have some program to regulate the energy efficiency of refrigerators (includes EU25) [2]. The most prevalent programs are mandatory comparative energy labeling and minimum energy performance standards (MEPS or efficiency standards). A majority of countries use both of these program measures in parallel. There are also a number of endorsement style labeling programs in operation around the world.

While refrigerators are now a product with a large international trade, different countries have poorly aligned test procedures. There are at least half a dozen different test procedures in force around the world and there are many national and regional variations to these predominant test procedures.

A traded product must generally comply with mandatory requirements in all the markets where it is sold and authorities in each market will usually ask for evidence that it does so. This means that a refrigerator exporter will need to have each model tested several times (or many times) to demonstrate that it complies with the relevant performance requirements as well as MEPS and/or energy labeling in each of the markets where it is sold. This can restrict the availability of many energy efficient products in many markets.

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 importation. This is also an operational nightmare for larger producers that want to trade in many markets.

Origin of Different Test Procedures

Many national and regional test procedures for performance for refrigerators (excluding safety, which is mostly standardized within IEC except for the USA) have been around for many decades. The main focus of these test procedures was originally the maintenance of suitable internal temperatures for the safe storage of food. This is usually assessed at different ambient temperatures to ensure that the refrigerator is capable of operating correctly in a normal range of household conditions. This assessment of operation at different ambient temperatures is still a key focus of many current test procedures and is core to the energy service which is provided by refrigerators. While many refrigerators were tested to assess their temperature performance, energy consumption measurements were not part of this assessment.

The first country to bring energy consumption to the testing forefront was Canada, which introduced mandatory energy labeling in 1978, followed by the USA in 1980[2]. The US reviewed their local test procedures and adopted an elevated ambient temperature (90°F which translates roughly to 32°C) to compensate for "normal use" such as door openings and the addition of warm food and drinks. The process by which this ambient was selected is unclear, but it has propagated into a number of other regional test procedures.

The various test procedures developed by ISO in the 1970s and 1980s settled on an ambient temperature of 25°C, which is somewhat warmer than normal use in Europe (thought to be about 20°C on average). Again, this higher than normal test temperature was probably intended to account for consumer use, although little documentation on its selection process is thought to exist.

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[2] Some European countries had voluntary energy labeling programs in the 1970s (eg France and Germany) [4] but these were not widespread or overly successful.

Prior to 1999, Japan had a unique refrigerator test procedure that tested the product at two ambient temperatures (15°C and 30°C) and it included a sequence of door openings to simulate actual use (JIS C9601)[13]. In an effort to harmonize test procedures, Japan adopted a local standard that was fully based on the ISO standard in 1999 (primarily ISO 8561 [12]) with test packages in the freezer and with no door openings. Within a year, Japan was unhappy with this test procedure and the associated energy results and added door openings to the test while keeping the ambient at 25°C. As a result of field trials during the period 2003 to 2006, which showed that energy consumption during normal use was considerably higher than the figures determined in the laboratory, Japan again changed its refrigerator test procedure back to the previous ambient temperatures with door openings, but now with the addition of warm drinks, warm test packages and ice making and the removal of ice during the energy test (defrosting energy is included in the test as well).

Korea and Taiwan have used an ambient energy test temperature for refrigerators at 30°C. These test procedures were in fact very similar to the early JIS test procedure but without door openings. Australia and New Zealand adopted a clone of the North American approach to energy testing in the mid 1980s (with the introduction of energy labeling) and used an ambient temperature of 32°C. Most other test procedures in the world are variants on these main approaches.

Critical Review of Energy Test Procedures for Refrigerators

The North American test procedure for energy consumption was separated from the performance tests at the time of government regulation. This is a desirable approach as assessing all elements of performance in a single test is not practical. AHAM[3], who owned the original test method, showed some vision and foresight into how frost free refrigerators operated. However, the North American energy test procedures, which are now incorporated in government legislation by direct reference, have changed little in the past 25 years, and this is presenting new problems (the US DOE regulations still reference the 1979 edition of the AHAM standard). There are some inconsistencies in the US approach: for example separate freezers (even frost free products) still retain test packages (moist sawdust, not ISO test packages) and the fresh food target temperature for energy tests on combination refrigerator-freezers is an alarmingly warm 7.22°C, which is highly dangerous in terms of food preservation. The poorly defined temperature requirements in the US test method in some cases has lead to the inclusion of inflexible user controls on low end products supplied to the local market, which tend to perform poorly from a temperature perspective (even if they are relatively efficient in accordance with the test method). Another issue is that the adaptive defrost algorithm, although admirable in its intent, gives quite ridiculous default values under some conditions, which results in unrealistically long defrost periods for energy consumption calculations.

Up to 2000, there was very little input into the ISO refrigerator committee from outside of Europe, so the ISO standards remained strongly oriented towards European style direct cooling products. An ISO standard to cover frost free (forced air) products was not published until 1995 (ISO 8561), and many frost free dominated countries outside of Europe resisted its adoption as there were significant problems in its use (partly arising from the inexperience of Europeans with this technology). A critical flaw in the ISO test has always been that it attempted to combine the energy test with the temperature performance tests. These tests specify freezers loaded with test packages (to simulate consumer loads) and therefore present huge problems for energy testing. Firstly, a large freezer load can take weeks to stabilize at each temperature setting, meaning that energy tests are very slow and potentially have poor reproducibility if full stability is not reached. The other fundamental problem was the definition of freezer temperature in the ISO test – this is defined as the warmest temperature of the warmest test package during the stable operation of the refrigerator. This temperature bears little relationship to the average temperature in the compartment, which is in fact the key thermodynamic driver for energy consumption. Energy testing of frost free products with a large freezer test package load presents another raft of testing related problems.

The new Japanese test procedure for refrigerators (JIS C9801-2006 [13]) is in many ways superior to most other test procedures because it subjects the refrigerator to a range of real processing loads to which the refrigerator has to respond in order to maintain internal temperatures. Another good aspect of the Japanese test procedure is the assessment of energy at both 15°C and 30°C ambient

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[3] Association of Household Appliance Manufacturers.

temperatures, which could be considered a typical range of normal use temperatures. Despite the many good elements to the Japanese test procedure, it has some significant drawbacks. Firstly, implementing door openings during an energy test presents a range of operational and strategic problems and most test labs are highly resistant to the prospect of having to instigate this regime during normal tests. The rate of door opening and the control of ambient humidity become critical. The other problem is that the heat load resulting from door openings and food/test packages (and ice making) in the JIS test is quite large and presents a significant “processing load” for the refrigerator during the energy test. While this in itself is not necessarily a problem, there are issues. The processing load varies somewhat depending on the product size and there are step changes in the loads added (multiples of 500ml bottles, multiples of test packages), which makes direct comparisons between similar products difficult. The other problem is that the loads are added during the recovery after a defrost period and many refrigerators are unable to fully recover from the effects of the added processing load before the next defrost, so it is not possible to separately assess the affects of the added processing load on the steady state energy consumption. The ability to do this is critical if the processing load is to be more generic so that it could be adapted for use in different countries.

In Australia and New Zealand, AS/NZS4474 has been developed on a continual basis over the past two decades and now contains many elements of test procedure best practice [11]. However, it is now understood that the energy test condition is not representative of normal use (see following section). While there is a desire to improve this element of the test procedure in AS/NZS, there is currently no international or regional test procedure that is an improvement over the current approach. For a small market like Australia and New Zealand, it is not realistic to develop a new test procedure from scratch, especially for global products such as refrigerators.

Changing test procedures and regulations is a slow process, especially for a high profile product like refrigerators, which are widely regulated. For a new test procedure to be adopted, regulators would need to be convinced that the procedure would deliver substantial long term advantages over their current approach. At this stage, no test procedure for refrigerators is suitable for global adoption.

A detailed review of many refrigerator test procedures can be found in [10]. Based on extensive analysis of refrigerator test data, it can be stated definitively that the use of an elevated temperature does not accurately compensate for heat loads during normal use. The reasons for this are explained in a later section of this paper. The approach of using an elevated temperature for energy tests is fundamentally flawed. The other observation is that products tend to have their energy consumption optimized for the test procedure to which they are designed [16]. While this is hardly surprising, it means that test procedures which can not estimate normal use will most likely provide a poor indication of efficiency and relative energy during normal use.

What Should a New Refrigerator Energy Test Procedure Deliver?

The objective of a product test method can be set out in general terms using some standard goals as stated by the IEC. Ideally a test procedure should be:

- Repeatable (same result on the same product in the same lab on retest): this is a combination of the test consistency and the product behaviour or consistency;
- Reproducible (same result on the same product in different labs): repeatability plus inter-laboratory differences;
- Technically simple but able to cope with new and emerging technologies;
- Inexpensive, avoiding the need for very expensive specialized equipment where possible;
- Quick as practicable;
- Reflective of consumer use and consumer relevant.

While all of these objectives are clearly desirable, some of these tend to be mutually exclusive for some products. This is especially so for refrigerators.

Understandably, regulators have focused on the issue of reproducibility, as this is a key element that underpins the enforceability and integrity of their programs. A test procedure that cannot be reproduced cannot be reinforced. So this been a fundamental requirement for all test methods.

In terms of simplicity and low cost, testing of refrigerators has never fulfilled these objectives. Tests have always been expensive, slow and complex. Refrigerators are a complicated thermodynamic product, the energy service is difficult to accurately assess, and accurate control and measurement of ambient and internal temperatures is required. However, the most up-to-date test procedures use sophisticated data logging equipment, which makes analysis more accurate and faster.

Unfortunately, historically little attention has been given to the issue of consumer relevance and accurately representing actual use. This is astounding for a product that accounts for such a significant share of household energy around the world. Part of the reason is that this is very difficult to do.

For technical programs that set an efficiency hurdle (such as MEPS), the need to reflect actual use is less important, as long as the relative value derived from the test method is reflective of the value derived in actual use. For energy labeling, where the energy consumption is declared and compared by consumers, it is more important to use a number that is closer to actual use where possible. At worst, the relative energy performance and ranking in the test procedure needs to be similar to the ranking in actual use.

Field data suggests issues with most of the current major test procedures in terms of both relative ranking and absolute energy consumption of products as shown on energy labels and as used. But analysis of field data is very complex as energy consumption is affected by both changes in ambient temperature inside the home and the amount of processing load (use) by the individual household. A review of in use energy consumption data for refrigerators shows:

- Australia, 1990 – 10 refrigerators measured in the lab at the start, after 1 year and after 2 years and used in typical homes between tests. Results: average in use energy was 80% of the label value (AS/NZS, 32°C ambient), but varied ±20% at a model level [5].
- Europe, 1998 – 100 refrigerators monitored in homes for 1 year. Results: average in use energy was 100% label value (EN153/ISO, 25°C ambient), but the standard deviation was ±18% at a model level [7].
- Sweden, 2006 – 13 refrigerators monitored in homes for 1 year. Results: average in use energy was 100% label value (EN153/ISO, 25°C ambient), but the variation was as much as ±50% at a model level [6].
- USA, 1990 – 209 refrigerators monitored in homes for 1 year. Results: average in use energy was 95% label value (AHAM HRF-1, 32°C ambient), but the variation for individual units was as much as ±60% from the energy label value for that model [8].

A household survey in Japan over several years was particularly interesting. When compared to the energy consumption in the laboratory (using the ISO test procedure or ISO with door openings) over the period 2001 to 2004 it was found that in use energy consumption could be as much as 300% (or more) of the labeled value. A selection of data is shown in Figure 1 [9]. Further investigations found that the single ambient temperature of 25°C was partly to blame, but it also became evident that some manufactures had programmed their refrigerators to recognize the test procedure and switch off various heaters and other energy consuming auxiliaries when it detected an energy test. This dramatic mismatch between laboratory and in use energy prompted changes to the JIS test procedure in 2006 as noted above, which reverted to two ambient temperatures plus door openings and added processing loads.

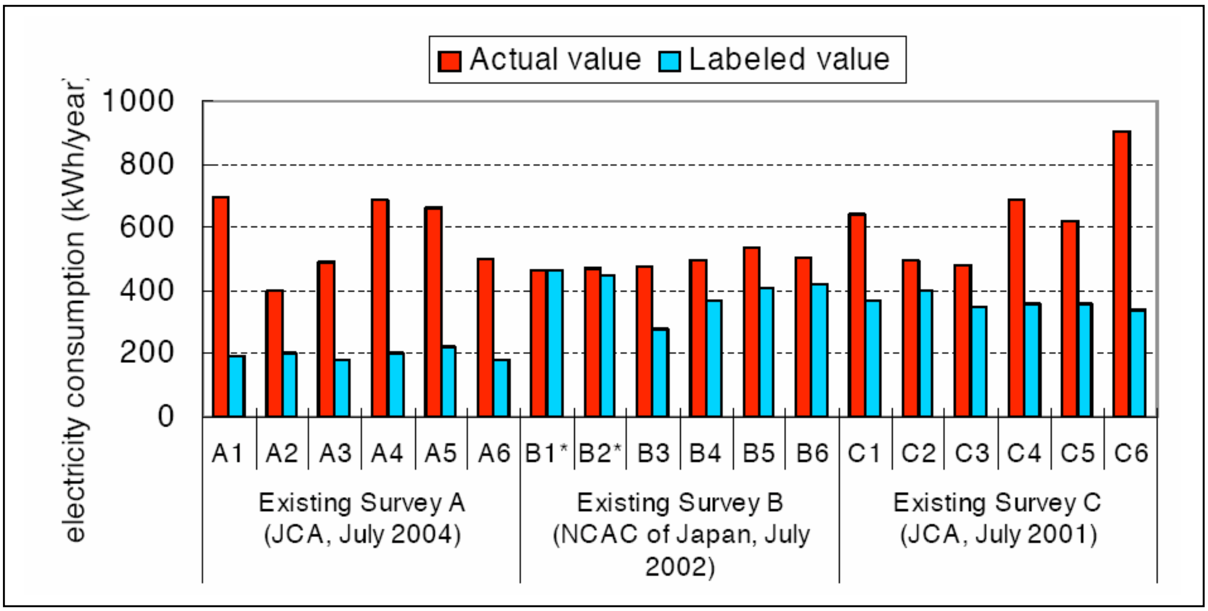

Figure 1: Actual (in use) energy consumption versus labeled (laboratory) values, Japan

With the advent of sophisticated electronics in many appliances, it is becoming increasingly difficult to stop or even detect circumvention (cheating) during an energy test. This suggests that test procedures need to be more realistic in nature (more like normal consumer use) in order to avoid these problems. With respect to refrigerators, the most common form of circumvention is switching off heaters (eg anti-sweat heaters or heaters associated with icemakers) during an energy test. But there are other strategies, such as the artificial delay of defrost periods during a test, which could deployed in order to obtain an unrealistically low energy consumption during an energy test.

The complication is that test procedures need to encourage and reward smart controls that save energy during normal use (eg anti-sweat heaters which are operated in response to ambient conditions, adaptive defrost controls that reduces defrost energy consumption during low use periods) but penalize, or at least not reward, controls that save energy only during the energy test. This is not as easy as it sounds, particularly if the test procedure is not close to normal use.

Energy Impacts of Normal Refrigerator Use

There are a number of factors that affect the energy consumption of a refrigerator. The most important of these are:

- Ambient temperature;
- Processing load from the addition of warm air and humidity through door openings and processing load from the addition of food and drink to be cooled (effectively, the efficiency of the refrigeration system);
- Internal compartment temperatures (user settings);
- Design and energy associated with the defrost and recovery (for defrost free products);
- Impact of additional internal humidity in terms of the response of the defrost system (including frequency of automatic defrost cycles) to remove this moisture;
- Additional user related features such as ice and water dispensers, additional doors, multiple compartments and special use zones;
- Possible longer term deterioration in energy performance with age (wear and tear, failure of components) – this factor has not been assessed in this paper.

Ambient temperature effect

Test data for nearly 100 refrigerators has been analyzed as part of the development of a new international test procedure. This analysis demonstrates that the ambient temperature effect has by far the largest influence on a refrigerators' energy consumption. The energy consumption of most refrigerators roughly doubles from an ambient temperature of 15°C to an ambient temperature of 30°C. However, the relative ranking in terms of energy consumption often changes across different ambient temperatures. This is illustrated by Figure 2 which shows the steady state power consumption[4] of six similarly sized bottom mount refrigerator-freezers at different temperatures. While the energy consumption response to ambient temperature is similar for all models, the relative ranking of units changes with temperature. It also illustrates that a test result at 32°C (or even 25°C) may bear little relation to actual or relative energy at 15°C. Even more interesting is an examination of the slope of the power curve in terms of power increase per degree C temperature rise as illustrated in Figure 3. This demonstrates that the slope can range from an increase with increasing temperature for some models to a decrease with increasing temperature from other models. Analysis of temperature response curves for 70 models show temperature response slopes ranging from 1% per degree C to 9% per degree C and slopes can increase, decrease or remain steady across different ambient temperatures [15]. This illustrates that energy measurement at a single ambient temperature may not provide a representative measure of energy use over typical ambient temperature changes. A famous engineer once said "you can't guess the slope of a line from a single point"; nor can you guess the shape of a curve. A full temperature response curve across all likely operating ambient temperatures would be ideal.

One of the largest underlying drivers for the lack of harmonization of refrigerator test procedures around the world is the basic understanding that ambient temperatures have a significant impact on the energy consumption. Tropical countries and those with hot climates are reluctant to embrace a test at a low ambient temperature and many other countries see a high ambient test temperature as irrelevant. The reality is that refrigerators are subjected to a range of ambient temperatures during normal operation and the median temperature will vary by climate (but it also depends on the climate conditioning in households). Only a new test procedure that can provide relevant energy performance data for all climates will be globally relevant.

Processing load

The second most significant influence on energy consumption of refrigerators is processing loads from door openings and the addition of warm food and drinks. The only test procedure to attempt to measure this impact is the Japanese JIS C9801. The door opening regime is 35 openings for fresh food and eight for the freezer per day, conducted at 8 minute and 40 minute intervals respectively. Load added is 125g of ISO freezer test packages for each 20L of freezer volume and 500ml of water in bottles for each 75L of fresh food volume. As an example, a refrigerator with a 100L freezer and a 300L fresh food compartment would have 625g of freezer test packages and 2000ml of water introduced during the test. Introduced loads are at the ambient test temperature.

Test data for ten Japanese refrigerators at 15°C and 30°C shows that the energy impact of the processing load, which includes the addition of warm drinks, test packages and door openings, ranges from 10% to 40% of the steady state energy consumption, depending on the particular model. While the variation is partly due to differences in JIS loads for different sized units, further examination found that the apparent marginal coefficient of performance (COP)[5] of a range of refrigerators varied from as low as 0.5 to as much as 2.0. Therefore the efficiency of processing loads varies by a factor of up to four between different models for the ten models evaluated. Even if their temperature

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[4] Steady state power consumption in this case does not include any additional energy associated with defrost and recovery, the frequency of which can vary with changes in ambient temperature or usage.

[5] The apparent marginal COP is calculated as the ratio of the enthalpy change of the water placed into the refrigerator (to change it from ambient temperature to the operating internal temperature, including any phase change) divided by the additional energy required by the refrigeration system to remove this heat.

response curves were the same, these units would display remarkably different energy consumption behaviour during normal use as the energy needed to process these loads would vary considerably.

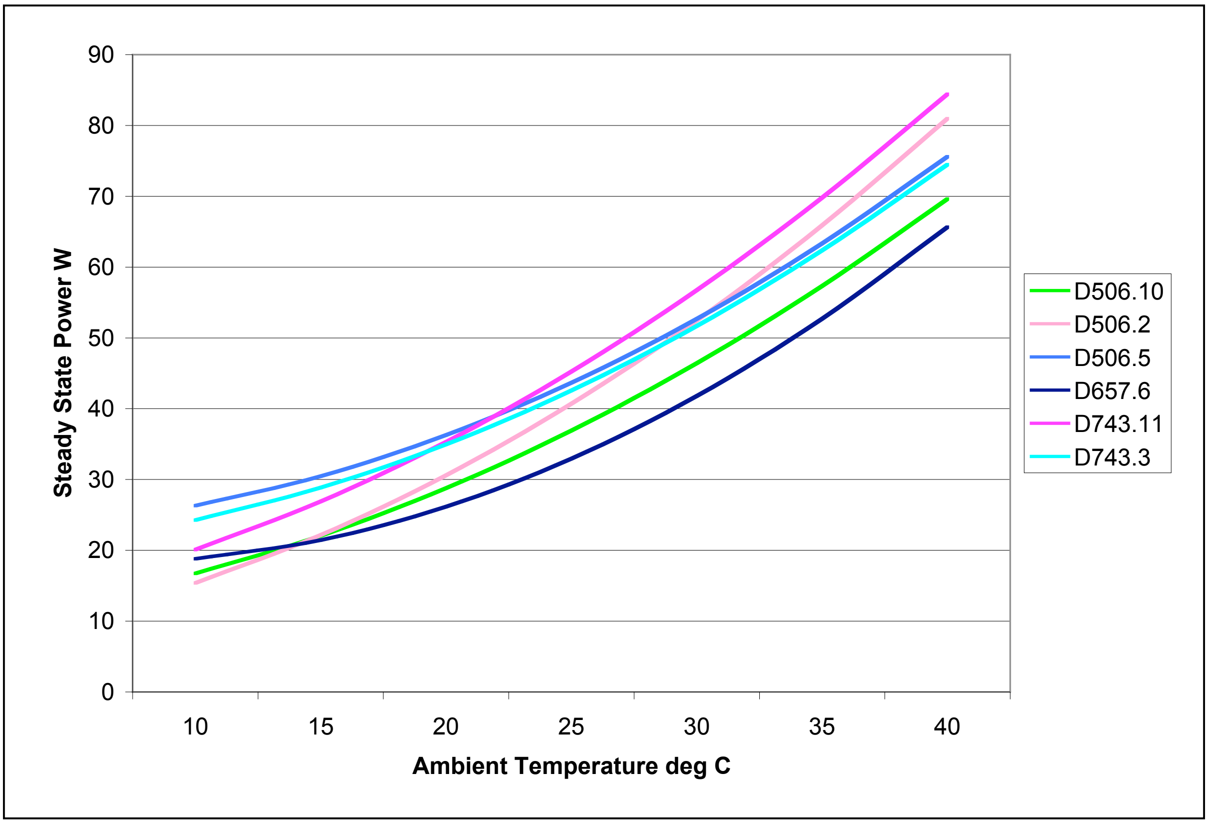

Figure 2: Energy temperature curve for 5 bottom mounted frost free refrigerators (<400L)

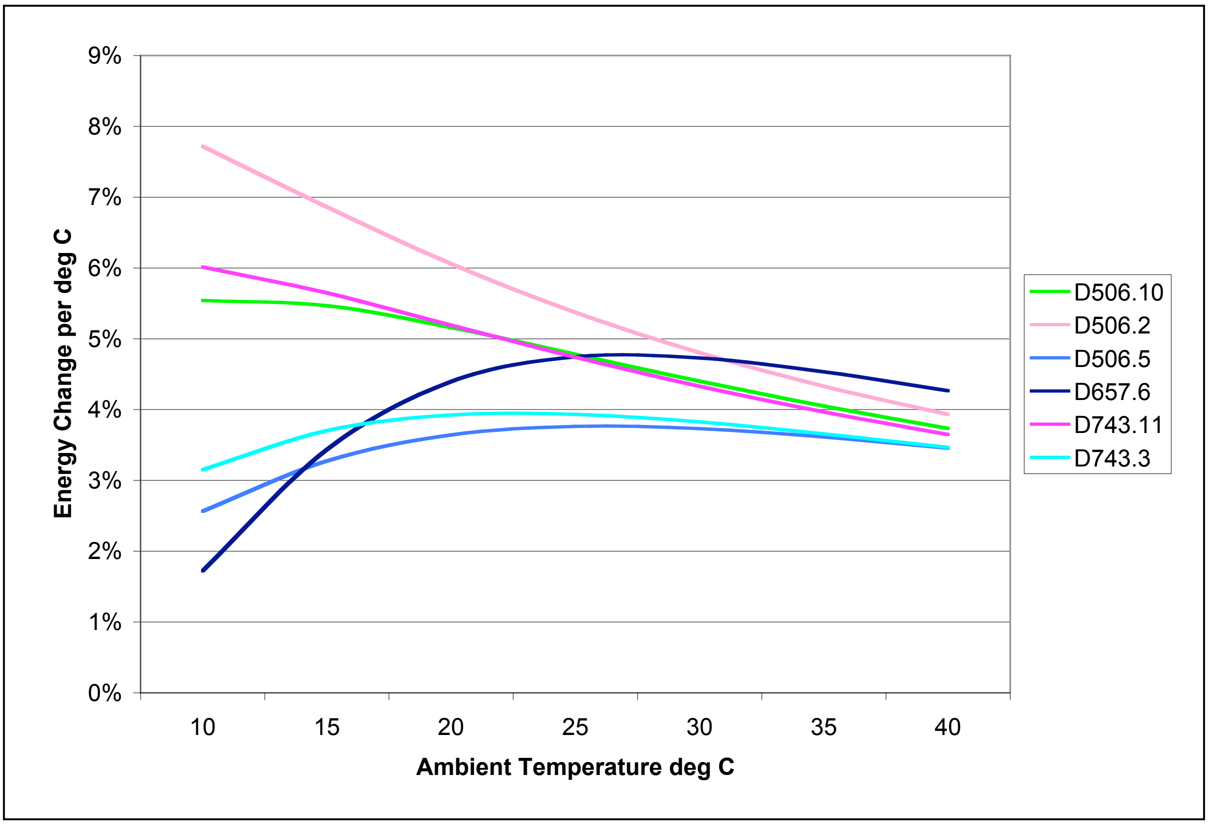

Figure 3: Energy temperature slope for 5 bottom mounted frost free refrigerators (<400L)

The problem with a test procedure that only assesses energy consumption without any processing load is that it skews designers towards insulation rather than improved refrigeration processing efficiency.

Detailed psychrometric calculations have been undertaken to quantify the relative impact of the different processing load elements in the JIS test procedure [15]. These processing loads are made up of:

- Sensible cooling of warm air introduced from door openings;
- Latent cooling of moisture introduced from door opening plus formation of condensate;
- Cooling of water (fresh food) and test packages (freezer);
- Making of ice (where an icemaker is present).

These are illustrated in Figure 4 at an ambient temperature 32°C and compartment temperatures of 4°C and -18°C. Typically, door openings account for more than half of the total processing load on the refrigerator while cooling of water makes up another 15% or so, meaning that fresh food loads are about 70% of the total load at an ambient temperature of 32°C. At an ambient temperature of 16°C (the proposed IEC lower ambient test temperature), the fresh food load share falls to about 50%. These calculations demonstrate that door openings are a significant usage element for refrigerators.

Most importantly, the refrigerator sees the entire processing load resulting from these elements as an internal heat load. The origin of a heat load should not really matter during a laboratory test (apart from the disposal of condensate during defrosting). So it may be possible to avoid a sequence of door openings (a major component) through alternative heat loads deployed during the test.

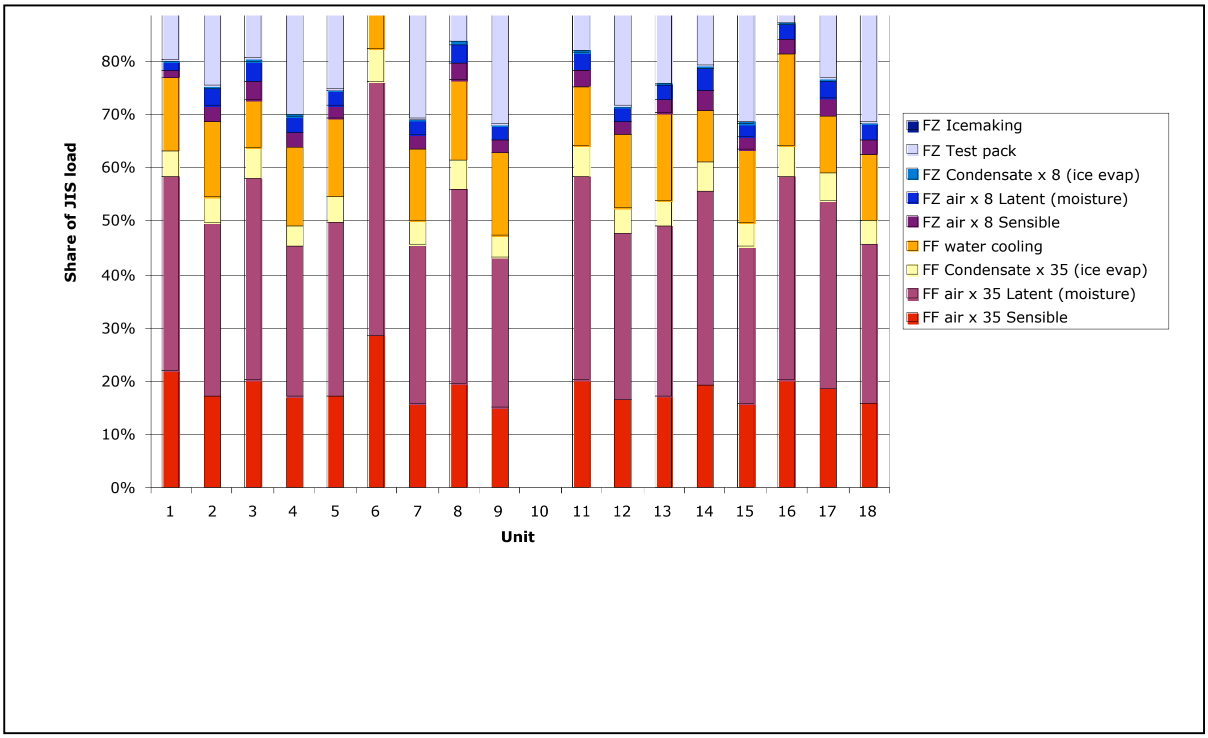

Figure 4: Share of processing load for 18 refrigerators, JIS test procedure

To accurately assess the impact of processing load during normal use, refrigerators must be monitored in people's homes. However, assessing the impact of processing load on energy consumption and separating this from ambient temperature effects and defrost frequency through end use measurements is complex. Ideally energy data is required at 1 minute intervals[6] as well as ambient temperature data adjacent to the refrigerator (this can be collected less frequently). To assess the processing load, an accurate temperature energy curve for the particular refrigerator being metered needs to be determined as well as the marginal efficiency of the refrigeration system. Unfortunately, these data are available for very few refrigerators and the analysis of in-use metering data to assess the processing load is complex. All field trials of refrigerators to date have measured total energy over a year and attempted to compare this to labeled or laboratory energy values. No previous field trials have attempted to quantify the impact of processing load or ambient temperature on total energy consumption.

How realistic are the JIS door openings? Data on door openings was obtained from 48 refrigerators in the USA, New Zealand and Australia over an average period of 243 days each (total 13,028 days of data). This evaluation showed that there were an average of 30.6 openings per day (SD=16) for the fresh food compartment and 4.5 (SD=3) for the freezer compartment (the statistical means for each country were similar), although the distributions for both of these values were quite wide [15]. This suggests that the JIS loadings are not so far away from typical use in some western countries.

Internal compartment temperatures

Another element that affects energy consumption of refrigerators is the user selected internal temperature. The impact of internal temperatures is significant in that some consumers may run their compartments colder or warmer than the recommended or standard value. Analysis of 30 refrigerators in Australia with separate controls for fresh food and freezer found that the typical energy impact of internal compartment temperature variations was about 3% to 4% per degree C for freezer temperature and 1% to 2% per degree C for fresh food temperature [17] when operating at an ambient of 32°C. The exact impact varies at a model level and depends on the system design and configuration. However, the potential maximum energy difference between individual units of the same model operating in the field is likely to be of the order of 10% or less for typical user selected internal temperatures.

Ability to operate in different ambient conditions

Another factor that can affect energy efficiency is any minimum performance requirements such as the ability to operate in extreme temperatures. For example, being able to maintain internal temperatures at an ambient temperature of 43°C requires a larger compressor when compared to a less stringent requirement (eg at an ambient of 32°C for temperate climates) – this larger refrigeration "capacity" means that operation during normal use (moderate ambient temperatures) will be somewhat less efficient unless a variable output compressor is used.

Defrost system design

The inherent design of the defrost system will determine the marginal energy impact of defrost and recovery. Some design strategies can minimize this impact. These include partial use of hot compressor gas in the defrost process and thermal isolation of the evaporator from the compartments. Isolation reduces leakage of any heat used for the defrosting operation into the storage compartments. Thermal isolation has two benefits. Firstly it reduces heat ingress into the compartments which has to be removed by the refrigeration system (resistive heating may therefore have a double energy penalty). Secondly it reduces any temperature rise during defrost which is important for food quality. Defrost operation is an inherent characteristic of each model and the user has only an indirect impact on the energy consumption associated with defrost and recovery (as a result of use and ambient conditions).

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[6] 1 or 2 minute data allows the total energy consumption per compressor run cycle to be accurately determined, which is required to assess steady state power consumption (in order to separate ambient temperature effects from usage effects). Longer monitoring intervals result in a large error in the average cycle power due to inaccuracies in the cycle time. This is only applicable to single speed compressors. Inverter driven compressors require other techniques.

Ideally, there should be a way of estimating a typical defrost period during normal use. For single speed compressors that use compressor run time, this can be readily calculated under different ambient temperature regimes and use regimes. Similarly, defrost controllers that run on a fixed time period (unusual, but they do exist) are simple as they do not change in response to any usage or ambient conditions. Adaptive controls are the most complex, as they respond to many variables in order to optimize the defrost period. Adaptive defrost controls are many and varied, but many use information such as compressor run time (or refrigeration output for inverters), ambient temperature and/or humidity, count of door openings and defrost heater time for the previous defrosts. Adaptive defrost controllers are good in that they theoretically minimize the frequency of defrosts for the particular usage of the appliance. However, this is an area where circumvention can be programmed into the product (eg if the product sees a stable specific ambient test temperature and no door openings, it is fairly easy to program a delay in the defrost – this can be hard to detect). While accurately estimating the defrost period in the field is desirable, it is important to note that a 100% error in this variable will typically result in a 5% energy error. So defrost period is important but is less critical than other parameters in terms of accurately assessing energy consumption during normal use.

A New Global Test Procedure for Refrigerators

A new globally relevant test procedure is needed. None of the existing national, regional or international standards for refrigerators assess the most important impacts of energy consumption, such as ambient temperature impact and processing load efficiency (apart from JIS, which has problems in terms of its global application).

After the publication of ISO15502 (now IEC 62552 [14]), ISO Working Group 2 agreed to start work on a new international test procedure to redress the shortcomings of the ISO standard. An additional goal was to make the test procedure more globally relevant in terms of its ability to deal with ambient temperatures and consumer use. In 2006, the responsibility for household refrigerator performance test procedures was moved from ISO to IEC at the request of IEC TC59. Working Group 12 under TC59 has been developing the new global test method since 2006, although progress has been slow. This is partly due to the complexity of the task, but is also due to resistance from some members as the new approach moves away from historical approaches. To some extent, this is understandable as manufacturers have invested heavily in designing their products to the current local test procedures and regulators regulate current products on the same basis. From 2006 to 2009, refrigerators did not have their own sub-committee within TC59 (now SC59M), so there has been a lack of leadership and guidance on development of this standard to date.

While there are many details still to be confirmed, the elements of a new global energy test method are being pieced together. The key elements where there has been at least some agreement are:

- General setup, instrumentation and tolerances – similar to AS/NZS4474.1-2007. Data recorded at 1 minute or faster, equal intervals.
- Fresh food air temperature sensors as per ISO, but some variants are under discussion in IEC. Freezer air temperature sensors as per AS/NZS.
- Internal compartment target temperatures for energy: -18°C (air average) for freezer, +4°C for fresh food, no test packages in the freezer (unloaded).
- Average temperature will be based on an average over the entire defrost control cycle.
- Test period starts at the beginning of a defrost period (once the steady state condition ceases: eg start of defrost heater or pre-cool before defrost) for frost free products.
- Internal temperatures – may calculate target temperatures by interpolation (triangulation or linear, depending on the number of controls).
- New volume measurement based on “what you see is what you get” (details being debated).

The agreement to average the temperature over the whole defrost control cycle is particularly important. This provides a strong penalty for products that allow excess heat to leak into the compartments during defrost and also offers a reward for pre-cooling of compartments prior to a defrost in order to maintain higher food quality by limiting temperature rises.

The debate over ambient temperatures for energy testing has been long and intense. Understandably, laboratory personnel want to minimize the combinations of requirements and fix temperatures at a point where they already test (16°C and 32°C are already used for European temperature operation tests). The use of fixed pre-defined points obviously simplifies testing. However, if the key output of the standard is a temperature energy curve for steady state conditions, then the ambient temperatures used to determine this curve are largely immaterial. In fact, given that all refrigerator responses are curves, it is highly desirable that 3 different ambient temperatures be used to determine the curve. The use of ranges of ambient temperature in the new standard (eg one point in the range 13°C to 18°C, one point in the range 22°C to 26°C, one point in the range 30°C to 34°C) would make it almost impossible for manufacturers to circumvent the test procedure as the refrigerator would be unable to work out whether it is under test. This is an important consideration.

An associated issue is that some refrigerators have heaters that operate in lower ambient temperatures or under some conditions. These heaters make the standard ambient temperature energy curve appear to have a discontinuity at the point where the heater operates. The operation of any such heaters needs to be taken into account when developing the temperature energy curve.

The working group is currently considering a proposal with the following elements:

- Determine P1 – power under steady state condition at particular ambient temperature and internal temperature setting (period between defrosts).
- Determine P2 – power of unstable period of defrost and recovery (expressed as additional energy in Wh over and above the P1 power level for the control setting).
- Determine P3 – power in response to a processing load added (expressed as addition energy in Wh over and above the P1 power level for the control setting).
- The processing load to determine P3 is a water load (at the ambient temperature) of 10g per litre of volume for fresh food and 3g per litre of volume for freezer: this is added to the compartment during steady state operation[7].

Detailed analysis of 70 refrigerators has found that the defrost and recovery energy is best characterized as a marginal energy consumption over and above the underlying steady state power consumption P1 for the particular ambient temperature and internal temperature setting. While there is a small random and usage associated element to the marginal defrost energy P2, the marginal energy is remarkably stable across all conditions of ambient temperature and internal temperature where expressed as energy consumption above P1. This means that data for two or three defrost and recovery periods are required to characterize this element of a refrigerator.

One area where there have been few concrete proposals to date is an approach to determine the time between defrosts during normal use. This is most critical for adaptive defrost systems that may use a number of use related parameters to adjust the defrost period. The most likely approach is the use of test data together with some specific tests or algorithms using manufacturer data to assess the response under more typical usage regimes.

An area that has not been discussed to any extent is the issue of assessing suitability of internal storage temperatures. While it is likely that a variant of the current ISO/IEC temperature storage test will be developed (with freezer test packages), the details are still open. It is widely agreed that assessment of storage temperatures for a refrigerator is a key performance element. An associated performance measure could be stability of internal temperatures over time and over different ambient temperatures (without the need for consumer intervention).

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[7] The fresh food compartment load is added in open plastic containers 500g max each. The freezer compartment load is added as water in ice making trays. Load is added after the unit has fully recovered from a defrost period; recovery from the addition of the load should be complete before the next defrost.

Conclusions

Refrigerators represent an important energy using product in households and the commercial sector throughout the world, resulting in widespread energy regulation. While there is a significant world trade in refrigerators, different test procedures are used in many countries. The current test procedures, with the exception of the Japanese JIS, fail to take into account the two most important aspects of energy consumption of a refrigerator – the response to changes in ambient temperature and the efficiency of processing of heat loads arising from normal use. None of the current test procedures is suitable for adoption as a global test procedure.

Detailed data analysis for refrigerators shows that the energy consumption (and perhaps more importantly ranking) can vary under different conditions. This means that energy labeling and MEPS (efficiency standards) are probably discouraging or even excluding some products from the market that are more efficient during normal use and encouraging the use of products that are less efficient during normal use. Refrigerators are almost universally optimized to perform best under the energy test procedure under which they are regulated. While their temperature operation under normal use may be satisfactory, their energy performance may be less than optimum. A new test procedure is needed.

While good progress has been made on a new global test procedure within IEC, there is still some distance to travel before the methodology and details are settled. In particular, details of how to determine an ambient temperature energy response curve and the addition of a processing load is still open. The other area that requires detailed work is research on typical usage in different regions around the world and approaches on how the parameters measured in a new global test procedure can be adapted to reflect typical use in different regions. Data on internal dwelling temperature distributions by region is also lacking. A new global test procedure promises a more accurate and relevant ranking of refrigerating appliances to provide better consumer information and to set efficiency levels based on more realistic in-use performance. For manufacturers, even though a new global test procedure may be more complicated than each of the existing test procedures, it will ultimately reduce the total testing burden on suppliers if a single global testing regime can be agreed. A global test procedure will also allow the identification and trade of the most efficient products into all markets, which will help to drive down global energy consumption.

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