Summary Overall Mapping and Benchmarking Approach to the Analysis of Domestic Refrigerated Appliances

The aim of this document is to provide an overview of the mapping and benchmarking process for analyzing domestic refrigerated appliances. It is designed to be read in parallel with separate documents that detail the specific actions taken for individual data sets supplied by each country[1].

1 Overview of the mapping and benchmarking outputs for domestic refrigerated appliances

The basic objective of the mapping and benchmarking process is to provide time series graphic and numeric information on domestic refrigerated appliances. The basic metrics to be presented in both the mapping and benchmarking documents are:

- The Average Unit Energy Consumption (UEC) of the appliances in kWh/year;
- The Average Unit Energy Efficiency (UEE) of appliances in kWh/adjusted litre/year;
- A comparative Energy Efficiency Index (EEI) for the appliances (benchmarking only);
- Total actual and total adjusted product volumes.

In addition, where possible, the analysis of a number of secondary metrics including percentage of products with ice maker, defrost functionality, etc. will be presented. As normal, this information will be published in two forms:

- A *Mapping* document – where the information is presented based on local conditions;
- A *Benchmarking* document – where testing conditions will be normalised to make product testing conditions comparable.

The analysis will be presented subdivided by functional product as follows:

Table 1: Categories used for the function grouping of products in the mapping and benchmarking of refrigerated domestic appliances

Refrigerator only and refrigerators with freezer compartments	The primary compartment is for fresh storage in the temperature range 5^{o}C >= T> 0^{o}C *and* • The unit has no freezer compartment, *or* • The unit has a freezer compartment of any temperature rating but a volume of less than 14 litres, *or* • The unit has a frozen food compartment of any volume that is rated as 0^{o}C >= T > -15^{o}C
Refrigerator/Freezer	The primary compartment for fresh storage in the temperature range 5^{o}C >= T> 0^{o}C *and* the primary frozen food compartment is greater than 14 litres and has a rated temperature T <= -15^{o}C
Freezer only	A unit where *all* compartments have a temperature rating T <= -15^{o}C

[1] The exception is Japan where a special approach has been necessary. Due to the very different test method employed in Japan (refer to the Japanese mapping document), data was supplied in a form normalised to the IEC test methodology by the Japanese Electrical Manufacturers Association. Therefore, only the section on calculation of Energy Efficiency Index (EEI) is applicable to Japan.

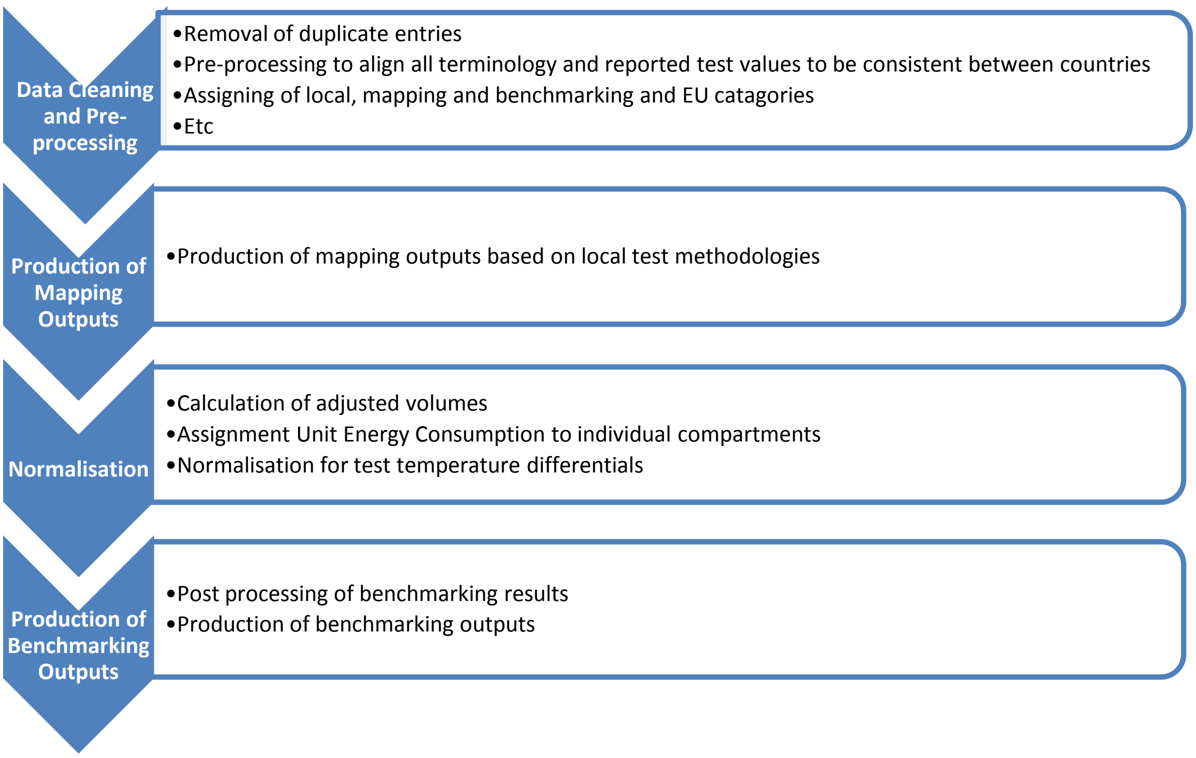
Normalised results are to the requirements detailed in the 2009 EU regulations[2] and the associated EN methodology. This benchmarking "standard" has been selected due to:

- The number of reporting countries that test to a similar set of requirements;
- The methodology being sufficiently flexible to work with all types of product configurations and the fact that it presents an adjusted volume methodology to account for variations in defrost type, etc;
- The inclusion of a methodology for the calculation of an Energy Efficiency Index (EEI) which has the flexibility to compare and combine all types of product size and configuration.

2 The mapping and benchmarking process for domestic refrigerated appliances

There are essentially 4 stages to the mapping and benchmarking process for domestic refrigerated appliances as detailed in Figure 1. Each of these stages are addressed in more detail in the following subsections.

Figure 1: Summary of stages in the mapping and benchmarking of domestic appliances



2.1 Data Cleaning and Pre-processing

2.1.1 Data cleaning

Data cleaning is best described as the process of aligning all data sets to be comparable with those received from elsewhere. This is country-specific, but includes actions such as:

[2] COMMISSION REGULATION (EC) No 643/2009 of 22 July 2009, effective July 2010.

- Converting data values from imperial measurement to their metric equivalents;
- Sub-dividing amalgamated data sets into individual years;
- Removal of duplicate entries where appropriate;
- Adjusting *reported* values to be equivalent to *test* values.

2.1.2 Pre-processing

The pre-processing of data:

- Assigns to individual models (or groupings) some basic categorisations that are used later in the analysis, principally the mapping and benchmarking categorisation as shown in Table 1, and the allocation of the closest equivalent EU product categorisation, but also allocation of characteristics such as defrost type, installation type, climate class and ice maker type. When specific data is not available, a number of assumptions need to be made to ensure these characteristics are captured in the most robust way possible.
- Allocates the compartments within the units to one of the six temperature compartment groups shown in Table 2Table 2. Where more than one compartment was reported with the same temperature, the net volume of the compartments is added together.

Table 2: Table for Allocation of Compartments by Temperature

Compartment 1	Compartment 2	Compartment 3	Compartment 4	Compartment 5	Compartment 6
14 °C>=T>5 °C	5 °C>=T>=3 °C	3 °C>T>-2 °C	-2 °C>=T>-9 °C	-9 °C>=T>-15 °C	T<=-15°C

2.2 Production of Graphical Mapping Outputs

Where possible, the following sales weighted and product weighted mapping outputs are produced:

- The Average Unit Energy Consumption (UEC) of the appliances in kWh/year;
- The Average Unit Energy Efficiency (UEE) of appliances in kWh/adjusted litre/year;
- Total actual volumes by fresh and frozen compartment and total adjusted product volumes.

For mappings, the UEC is the UEC declared locally following data cleaning. The adjusted volume (and consequentially the UEE) uses the local test methodology/regulation derivation. Where information is sales weighted, this is calculated by [Sum for all models (model variable*sales of model)]/total sales of all units. For example, sales weighted UEC is calculated as [Sum for all models (model UEC*sales of model)]/total sales of all models.

2.3 Normalisation

2.3.1 Normalisation Overview

The testing procedures to determine the UEC of domestic cold appliances are broadly similar within reporting countries (with the exception of Japan[3]). The testing procedure can broadly be described as follows:

- Units are placed within a temperature controlled environment, switched on and allowed to stabilise;
- The units are then operated for one or more time periods such that the time period captures a "normal operational cycle" of operation including defrost, etc;[4]
- The unit energy consumption is then converted to a 24 hour (or monthly/annual) energy consumption for that unit.

When attempting to "normalise" the UEC to account for differences in the test procedures between regions, the *primary* impact on energy consumption is the different internal compartment and the external (ambient) test temperatures[5]. However, a number of other factors have an impact including (although not limited to):

- Whether the unit has a "load" included during the test, how much load is included and where it is positioned;
- The specific procedures for accounting for defrost method;
- The settings for "dual temperature" use compartments and "ancillary" features such as ice makers, anti-sweat/condensate heaters;
- Where the units is positioned within the testing environment and how units that are designed to be "built-in" are tested;
- The approach to product operation that may be specifically designed to minimise consumption under test conditions;
- Tolerances for testing procedures and declared values.
- The benchmarking analysis is based purely on adjustment for internal and external temperature differences and does ***not*** account for any differences in other factors. This approach has been taken due to a combination of a lack of empirical evidence to identify the individual impact of the other factors (individually or in interrelation), and the lack of sufficiently detailed product information from reporting countries.

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[3] The Japanese test methodology is significantly different from elsewhere. In particular, it differs in the use of an average of two separate tests using different external temperatures, and has door openings and the insertion of a load during the test procedure. Therefore the normalisation approach presented in this document *does not* apply to Japan. Japanese data has been normalised directly by Japan to be comparable with IEC 62552 based on empirical data at their disposal and, at this stage, the accuracy of conversion cannot be verified. However, the section on calculation of Energy Efficiency Index (EEI) is applicable to Japan.

[4] Note that in recent years, product sophistication has increased and the capture of a "normal cycle" has become more complicated. However, most test methodologies/regulations define an approach to account for the potential product variations.

[5] Beyond the measurement of UEC there a large number of other differences in test methodologies. However, the only significant issue relevant to the mapping and benchmarking process is the measurement of compartment volumes. Methodologies/regulations vary in their requirements to declare total compartment volumes or net (usable) volume, and the methodology for calculating net volumes. However, the actual difference in resulting volumes using the different methodologies is marginal, typically 1-3%. Therefore, provisionally the Mapping and Benchmarking approach is to consider declared compartment volumes as equivalent.

2.3.2 Allocation of declared UEC to compartments

A “conversion factor” may be applied to the declared UEC to normalise for the differences in test methodology internal compartment and external temperatures in comparison with second methodology. However, obviously compartments within the same unit operate at different temperatures (eg the fresh and frozen compartments). Therefore, the UEC has to be apportioned to each compartment to allow the application of the conversion factor relevant to the internal/external temperature differences of each individual compartment.

All reporting countries have developed a methodology for *adjusting volumes* for individual compartments. The adjusted volume seeks to create a factor that, when applied to the volume of the compartment, *approximates* the equivalent volume of a “standard compartment operating at standard conditions[6]” that could be cooled with the same amount of energy. Thus, UEC can be allocated to individual compartments to give “compartment EC” based on the ratio of the *adjusted* compartment volume to the total *adjusted* unit volume[7].

Thus, to enable the normalisation of UEC for differences in temperature, overall UEC’s are proportioned to give individual “compartment ECs” based on the local adjusted volume methodology. Normalisation for differences in test procedure internal and external temperature can then be undertaken for “individual compartment EC”.

However, while the general method for calculating adjusted volume is the same across all reporting countries, the specific details vary slightly. To ensure consistency across all countries in the allocation of energy to compartment, the EU methodology for adjusting volume has been adopted, *but* with the thermodynamic factor using local test temperatures. Therefore, the EU methodology being used to calculate $Adjusted\ Volume_{benchmark}$ for each compartment as follows:

$$Compartment\ Adjusted\ Volume_{EU} = Vc * Thermodynamic\ Factor * FFc * CC * BI$$

and,

$$Total\ Adjusted\ Volume_{EU} = \sum All\ Compartment\ Adjusted\ Volume_{EU}$$

where,

Vc is the measured storage volume of the compartment(s)
Thermodynamic Factor = [External test temp – Compartment test temp]/External Test temp-Fresh compartment test temp]
FFc is the frost free factor. The 1.2 factor applies only to frozen compartments with automatic frost free capability.
CC is the climate class factor, 1.2 for compartments rated as tropical climate class, 1.1 for compartments rated as sub-tropical climate class, and 1 for all other compartments.
BI is the factor for units that are designed to be permanently “built-in” to cabinets and when the unit width is less than 58cm. The factor is 1.2

However, given very few countries has been able to identify when models have been tested to a climate class beyond standard conditions, and similarly few countries had the data

[6] This is usually the “standard primary fresh food” compartment as defined locally.
[7] Total adjusted unit volume is the sum of the adjusted volumes of all unit compartments.

identifying units that would be allocated the built in factor, calculations for all products in all datasets will be based on the assumption that the climate class and built-in factors are 1[8]*.*

Allocation of declared UEC to individual compartments is then achieved through a simple proportion as follows:

$$\textit{Compartment EC} = \textit{declared UEC} * (\textit{Compartment Adjusted Volume}_{EU}/\textit{Total Adjusted Volume}_{EU})$$

2.3.3 Normalisation of "compartment EC" for test temperature variations and calculation of normalised UEC

For the normalisation of "Compartment EC", two factors are used. One factor accounts for the relative difference in internal compartment temperatures (Factor A), the second for external compartment temperature (Factor B). In each case the factor is based on each 1°C difference in test temperature. These factors have been developed by an Annex technical expert (Mr Lloyd Harrington) as detailed in Appendix 1 and the application of the factors in the analysis calculations has been checked by a second independent expert.

As noted above, provisionally all normalisation is to the EU regulations/EN test methodology. Hence, normalisation of "compartment EC" can now be undertaken as follows:

$$\textit{Normalised Compartment}_{EU\ internal} = \textit{Compartment EC} * \textit{Factor A} * (\textit{EU compartment temp} - \textit{local compartment temp})$$

$$\textit{Normalised Compartment}_{EU\ external} = \textit{Normalised Compartment}_{EU\ internal} * \textit{Factor B} * (\textit{EU external temp} - \textit{local external temp})]$$

where factors are applied in internal compartment and external temperatures relative to nominal EU test temperatures shown in Table 3.

Table 3: Nominal EU Compartment and External Temperatures

Compartment 1	Compartment 2	Compartment 3	Compartment 4	Compartment 5	Compartment 6	External
9.5 °C	5 °C	0 °C	-6 °C	-12 °C	-18°C	25°C

Therefore,

$$\textit{Total } \textbf{\textit{Normalised}} \textit{ UEC}_{EU} = \sum \textit{All Normalised Compartment}_{EU\ external}$$

Individual model Normalised UECs can then be aggregated to present product and sales weighted UEC.

2.3.4 Calculation of Normalised UEE

Normalised model UEE values are calculated based on:

$$\textit{UEE} = \textit{Total } \textbf{\textit{Normalised}} \textit{ UEC}_{EU}/\textit{Total Adjusted Volume}_{EU}$$

[8] If sufficient information becomes available on product performance related to climate class and built-in factors (or indeed the impact of ice maker), these issues will be investigated in a separate analysis.

where Total Adjusted Volume$_{EU}$ is the same adjusted volume methodology outlined in section 2.3.3, but with a thermodynamic factor now based on the EU test temperatures to which all models have been normalised, ie

Thermodynamic Factor = [External test temp – Compartment test temp]/External Test temp-Fresh compartment test temp]

= (25 – Compartment Temperature)/20

Individual model Normalised UEEs can then be aggregated to present product and sales weighted UEE.

2.3.5 Calculation of normalised EEI

An Energy Efficiency Index (EEI) is a mechanism through which products of different types as sizes can be compared. Again the EU method for EEI calculation is being used as follows:

EEI = (AEc/SAEc) x 100

where,

AEc = Annual Energy Consumption of the household refrigerating appliance

SAEc = Standard Annual Energy Consumption of the household refrigerating appliance of the same type and volume

Now

AEc = Total Normalised UEC$_{EU}$

and

SAEc = Veq × M + N + CH

Where,

Veq is the Total Adjusted Volume$_{EU}$[9]

CH is equal to 50 kWh/year for household refrigerating appliances with a chill compartment with a storage volume of at least 15 litres[10]

M and *N values* are given in the table below

Compartment types	*M*	*N*
Refrigerator with one of more fresh-food storage compartments	0.233	245
Refrigerators with a 0-Star Compartment	0.233	245
Refrigerators with a 1-Star Compartment	0.643	191
Refrigerators with a 2-Star Compartment	0.45	245
Refrigerators with a 3-Star Compartment	0.777	303
Refrigerator Freezer	0.777	303
Upright Freezer	0.539	315
Chest Freezer	0.472	286

Individual model EEIs can then be aggregated to present product and sales weighted EEI.

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[9] Noting that Veq excludes adjustments factors for Climate Class and Built-in as detailed earlier.

[10] Note that insufficient data was available from the majority of countries to apply this CH factor consistently. Therefore, the CH factor is assumed to be zero for all models in all datasets..

Appendix 1

Household Refrigeration: Energy impact of changes in ambient and internal temperatures

Prepared by: Lloyd Harrington based on material drawn from *Household Refrigeration Paper 3: MEPS3 in Australia and NZ – Preliminary Impact Assessment of New MEPS Levels in 2015*, unpublished. Original Paper prepared by Lloyd Harrington and Jack Brown, Energy Efficient Strategies, for the Australian Equipment Energy Efficiency Committee and Australian Department of Climate Change and Energy Efficiency. Additional analysis was also undertaken specifically for this task.

Overview of this Paper

This paper examines detailed test data to provide an estimate of two different factors:

- The impact on energy consumption of a change in internal temperatures from those currently used in Australia and USA to the internal temperatures specified in the relevant IEC standards;
- The impact on energy consumption of a change in ambient temperature from 32°C to 25°C in a test room (this excludes any estimate of usage impacts).

Test Method Differences

Under current regulatory requirements, the following internal temperatures are specified in a range of test procedures.

- Australia and New Zealand: freezer air temperatures of -15°C and fresh food of +3°C for all groups and compartments;
- USA: freezer air temperatures of -15°C for refrigerator-freezers and fresh food temperature of not more than 7.22°C for refrigerator-freezers (most operate cooler than this temperature), for all refrigerators a temperature of +3.3°C for fresh food, for separate freezers a freezer air temperature of -17.8°C (0°F);
- Europe/ISO/old IEC: Fresh food of +5°C (this may be now +4°C in some countries, eg France), and a warmest test package temperature of -18°C (in practical terms this means an average compartment air temperature of about -21°C);
- New IEC: freezer air temperatures of -18°C and fresh food of +4°C for all groups.

The following ambient test temperatures are currently specified:

- Australia and New Zealand: +32°C;
- USA: +32.2°C;
- Europe/ISO/old IEC: +25°C;
- Japan: +15°C and +30°C
- New IEC: +16°C and +32°C.

The follow data provides some guidance on how to correct for these differences.

Estimating Energy Impact of Changes in Compartment Temperatures – General Approach

Changes in freezer temperatures have a significant impact when converting from AS/NZS to previous ISO temperatures.

Firstly, analysis of test data in Australia provides some basis for estimating the energy impact per change in temperature (per K) by compartment type is provided. This should be applied to AS/NZS data initially.

A study prepared for E3 in 2007 (EES, 2007) was undertaken to assess the energy impact of changes to the test method in AS/NZS4474.1-2007. The test method change meant that temperatures were measured over the whole defrost control cycle period, including the defrost and recovery period. As a result, in most cases measured temperatures were expected to rise by around 0.2°C to 0.33°C in the freezer (with no measurable impact on fresh food temperatures). The study examined triangulation data for some 31 refrigerators and freezers to estimate the energy impact of changes per degree K in both fresh food and freezer temperatures. The analysis was based on raw data provided by Choice as part of their routine laboratory tests. The key data from that report is reproduced in the table below.

Table 4: Energy Impact per Degree Change of Compartment Temperature

Group	**No of Units**	**Energy Impact %/deg K Fresh Food**	**Energy Impact %/deg K Freezer**
5T	15	1.8%	2.8%
5B *	8	1.4%	3.2%
5S	6	2.1%	3.4%

* Excludes some results for this group. Source: EES, 2007

Such a small sample is considered inadequate for a broader study. EES examined all available test reports submitted with energy labelling registrations in late 2011.

Over the period September to October 2011, EES reviewed all refrigerator test reports that were attached electronically refrigerator and freezer registrations on the Australian online database. Test reports for some 1,196 models provided a total of 3,576 sets of test data (for refrigerators and freezers, test reports on 3 separate units for each model are required). Test reports were downloaded and reviewed by EES. Data was manually extracted and test points re-run through an analysis system set up specifically for this project. The following table sets out the number of individual models and test reports examined for each Group.

Table 5: Number of Test Reports by Group Where Data were Extracted

Group	1 Test Point	2 Test Points	3 Test Points	Total Models (estimated)
1	67	135	0	68
2	326	86	6	140
3	24	16	3	15
4	15	9	0	8
5T	403	351	339	365
5B	83	99	321	168
5S	79	51	317	149
6U	241	36	3	94
6C	154	253	0	136
7	64	95	0	53
Total	**1,456**	**1,131**	**989**	**1,196**

Notes: Number of total models was based on total test points test points divided by 3, as results on 3 separate units are required for energy labelling and MEPS.

One of the surprising things about these data is that a large proportion of registrations use fewer than the permitted number of test points to obtain optimum energy consumption. This is set out in the following table.

Table 6: Share of Test Points Used for Registration by Group

Group	1 Test Point	2 Test Points	3 Test Points	Models (estimated)
1	33%	67%	0%	68
2	78%	21%	1%	140
3	56%	37%	7%	15
4	63%	38%	0%	8
5T	37%	32%	31%	365
5B	17%	20%	64%	168
5S	18%	11%	71%	149
6U	86%	13%	1%	94
6C	38%	62%	0%	136
7	40%	60%	0%	53
Total	**40%**	**32%**	**28%**	**1,196**

Indicates number of test points less than optimum
Indicates number of test points is optimum

In summary, a total of 1,957 test data sets used less than the permitted optimum to estimate energy consumption (about 55% of all test data sets).
Data for each of the Groups were then analysed to provide information on the estimated energy impact of a change in the fresh food and freezer compartments (as applicable), to provide a better estimate of the impact of the test method changes with moving to a different test procedure.

For Groups 1, 2, 3, 4, 6U, 6C and 7, the values for the two test points were used to estimate an energy consumption impact per degree K temperature change.

For all groups a significant number of data points were excluded where there were obvious errors, where points were too close or where the triangulation data were too small or the wrong shape to reasonably estimate energy-temperature coefficient for each compartment.

For Groups 5T, 5B and 5S, models that had triangulation data were of the most interest as this can provide an independent estimate of the energy impact of changes in both the fresh food and freezer temperatures. Triangulation allows interpolation of two compartment temperatures in two dimensions, and interpolation of energy and temperature in a third dimension, to provide an estimate of energy for any selected compartment temperature combination.

After cleaning and filtering the data, the energy impact of changes in fresh food and freezer temperatures (as applicable) for all Groups was determined. These are summarised in the table below.

Table 7: Summary of Energy Impact per Degree K Change in Compartment Temperature by Group

Group	Number of Records	Average FF %E/K	Std Dev FF %E/K (%)	Lower FF %E/K	Higher FF %E/K	Average FZ %E/K	Std Dev FF %E/K (%)	Lower FZ %E/K	Higher FZ %E/K
1	120	5%	0.024	2%	8%				
2 *	78	6.5%	0.020	5%	9%				
3 *	19	6.2%	0.014	4%	8%				
4 *	9	4.4%	0.013	3%	6%				
5T	188	1.8%	0.011	0%	4%	3.0%	0.092	1%	5%
5B	195	2.1%	0.013	0.5%	5%	2.7%	0.013	0%	4%
5S	209	1.3%	0.080	0%	3.5%	2.8%	0.011	0.5%	4.5%
6U	39					5.0%	0.019	3%	6%
6C	253					4.3%	0.019	2%	6.5%
7	95					4.0%	0.017	1.5%	6.5%

Note: All values shown are energy increase per degree K decrease in compartment temperature.

As illustrated from the table above, the energy impact resulting from the test method change will vary at a model level. The actual impact varies considerably depending on product design. It is not clear what the critical factors may be, but it is likely to be the balance of refrigeration system efficiency and overall insulation levels that play an important role.

When the temperature change impact for Groups 5T, 5B and 5S are considered in total, on average these are also around 5% per degree K in both compartments. So on average all Groups have an average energy impact of approximately 4% to 5% per degree K temperature change, except for Groups 2 and 3, which tend to have a smaller volume and hence could be expect to have slightly higher impacts per degree K change (due to the higher surface area ratio).

Applying these Factors to Model Data

The factors above are based on the analysis of test reports for some 1000 models registered in Australia. It is clear that the actual impact at a model level will be highly variable and it is not possible to predict with any accuracy the energy for individual models based on these factors. But these factors may give a broad indication of energy impacts across the population of models.

The factors provided assume that each model has perfect temperature control and temperature balance capability and that the newly desired target temperatures can be achieved simultaneously in both compartments. While this is probably true for most products available on the Australian market, this is certainly not true of many products in the USA or in Europe. Often these products are designed to hit the relevant target temperatures in both compartments under the locally specified test condition and many are not capable of changing the temperature balance under other test method conditions. These products would appear to have higher than expected energy under any test condition other than the one to which it is designed. This is in fact a severe limitation of converting from the conditions of any one test procedure to conditions and requirements under another, especially as test procedures do not record the information that is usually required to perform such a conversion with any accuracy.

The other factor that makes these types of conversion rather imprecise is that a substantial number of products in Australia (about 55% of all registrations as noted above) use fewer test points that the permitted number that may be required to get an optimum test result. This means that (in Australia at least) that about half the products have a recorded energy consumption value that may well be somewhat below target temperature (for example a single test point at -16.5°C is acceptable for a separate freezer in Australia, even though the target temperature is -15°C). This may be because the product cannot reach the target temperature or because the supplier wanted to save money and only conduct one test at a single point. In either case, the required temperature change to reach a colder freezer temperature under a different test method may be less than if the energy is assumed to start at the target temperature is -15°C. The actual temperature in each compartment for each test point is not recorded in the Australian registration system so these data are not readily available. The converse is true for fresh food, which is colder in Australia than ISO/old IEC.

Table 8: Recommended Energy Factors and Scale to Apply to AS/NZS data

Group	Average FF %E/K	Adjustment FF K AS/NZS =>ISO	Average FZ %E/K	Adjustment FZ K AS/NZS =>ISO
1	-5%	+2		
2	-6.5%	+2		
3	-6.2%	+2		
4	-4.4%	+2		
5T	-1.7%	+2	-3.0%	-5
5B	-2.4%	+2	-2.7%	-5
5S	-1.5%	+2	-2.8%	-5
6U			-4.0%	-4
6C			-4.3%	-4
7			-4.0%	-4

Note: All values shown are energy change per degree K change in compartment temperature. A 2% increase in FF temperature for Group 1 would result in a 10% decrease in energy (ie -5%E/K multiplied by a +2 degree Kelvin difference).

Impact of Ambient Temperature Data

Ambient temperature impacts are quite large and there is only very limited data available that can be used to estimate these impacts.

The energy consumption is affected by two main factors:

- The heat gain through the walls of the refrigerating appliance – this increased directly in proportion to the temperature difference between the inside and outside;
- The efficiency of the refrigeration system – this decreases as the temperature difference between the condenser (set by the ambient temperature) and the temperature of the evaporator (set by the coldest compartment) increases.

The heat gain into each compartment can be expressed as a linear function of the surface area and the temperature difference between the compartment and the ambient air. Calculating the net surface are of each compartment is very complex. And confounding this is the fact that the insulation thickness in each compartment (which varies by compartment) determines the actual heat flow. But as a general rule, manufacturers thicken the insulation on compartments that operate at colder temperatures, so as a first order approximation the volume of each compartment can be used as an indirect proxy for the surface area and insulation value for each compartment in most cases. The insulation value of a compartment is always fixed by the design and construction.

While the heat gain into each compartment is a different linear function, the sum of a range of different straight lines is also a straight line (where there are multiple compartments).

As an approximate estimate, it is possible to estimate the change in heat gain from a change in ambient temperature alone as follows:

$$E_{new} = E_{old} \times \left[\frac{\sum_{i=1}^{n} (T_{am} - T_i) \times V_i}{\sum_{i=1}^{n} (T_{at} - T_i) x V_i} \right] \qquad \textbf{Equation 1}$$

Where:

E_{new} is the energy at the new ambient temperature;
E_{old} is the energy at the original ambient temperature;
T_{at} is the original test room ambient temperature;
T_{am} is the new test ambient temperature;
V_i is volume of compartment *i* to *n*;
T_i is the measured temperature in compartment *i* to *n*.

NOTE: This correction is should only be applied to the steady state power, but we have no way to estimate this component. But for most frost free products, this makes up 90% of the total energy.

This correction is only really intended to be applied across small changes in ambient temperature. It assumes that there is no change in compartment temperature.

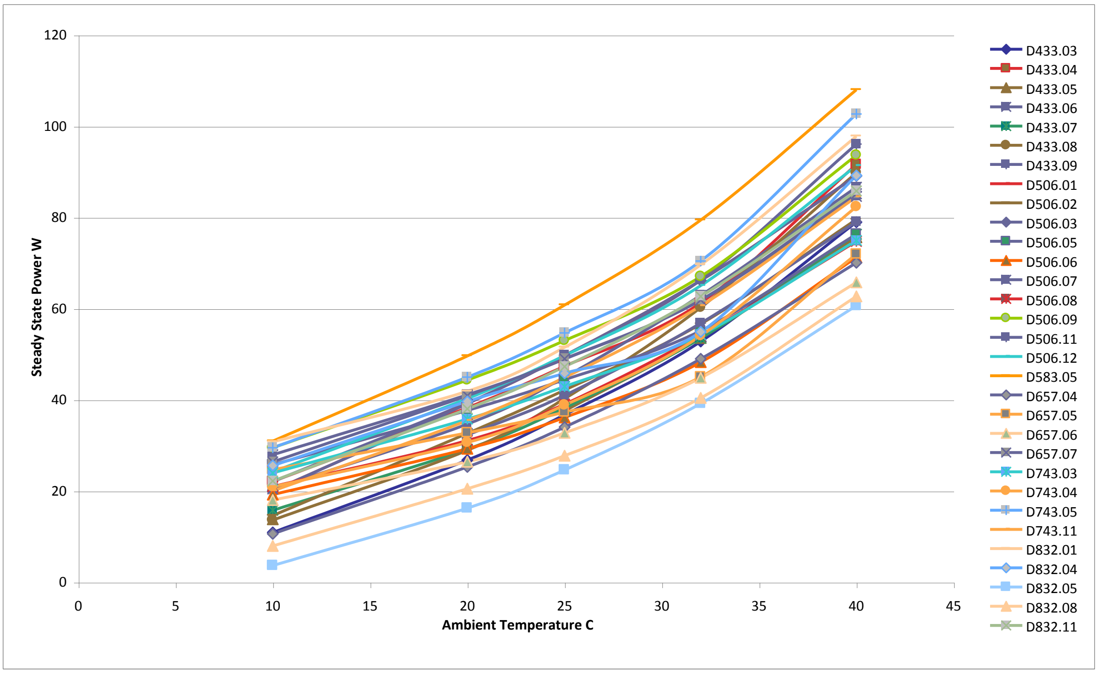
There are a range of other factors that can have a strong effect on energy consumption at different ambient temperatures:

- The most significant as noted above is changes in the COP of the refrigeration system as the condenser temperature increases with increasing ambient temperature;
- Changes in the operation of some auxiliaries (eg internal heaters to maintain energy balance, when tend to operate more at lower ambient temperatures, which can make data discontinuous in some cases);
- Drift in the internal temperatures during operation (the test data available was unadjusted for internal temperature at each ambient so this could affect some models);
- Changes in the startup losses due to different cycle lengths and compressor run times as ambient temperatures change.

The first factor should be smooth (but not linear) in its effect. The next two factors will result in some non linear effects in the data. The last factor should be included in the data as long as the changes are smooth with ambient temperature.

Data for some 30 models was examined. All of these models had data on energy at four different ambient temperatures (10°C, 20°C, 32°C and 40°C). An equation was fitted to the lower three ambient temperatures (10°C, 20°C and 32°C) in order to interpolate accurately at an ambient temperature of 25°C. A range of frost free refrigerator-freezers was examined with data for two Group 7 (frost free freezers) and two Group 1 (all refrigerators). An overall impression of the data is shown below.

Figure 2: Change in Steady State Power with Changes in Ambient Temperature



Using the above equation, the slope of the temperature gain equation can be estimated at an ambient of 32°C and an ambient of 25°C. The slope at these two points can then be averaged to get the expected slope due to heat gain alone when moving from an ambient temperature of 32°C to an ambient of 25°C.

For example, fresh food of 300 L at +4°C and 100 L freezer at -20°C would be:

$$E_{slope32} = \frac{[(33-4)\times 300 + (33-(-20))\times 100]}{[(32-4)\times 300 + (32-(-20))\times 100]}$$

= 1.0294

$$E_{slope25} = \frac{[(26-4)\times 300 + (26-(-20))\times 100]}{[(25-4)\times 300 + (25-(-20))\times 100]}$$

= 1.0370

The average slope between these two ambient temperatures is 1.0332 or 3.32% per degree K.

Therefore the ratio of energy from an ambient of 32°C to an ambient of 25°C in this example from heat gain alone is:

1/ (1-0.0332)^7 = 1.2668

Note: It may be possible to calculate the slope at the mid point between the ambient temperatures in order to estimate the average slope between the two ambient temperatures.

Undertaking this correction is useful as it takes account (to some extent) of different volumes and temperature of operation for each model.

When we look at actual data for a range of models, we find (as expected) that the energy ratio between an ambient of 32°C and an ambient of 25°C is somewhat larger than predicted by the heat gain alone. This is expected as the efficiency of the compressor will decrease with higher ambient (although not by a large amount). Typically the temperature gain factor has to be increase by a factor of 1.05 to 1.10 in order to correct for the changes in compressor COP (as well as some of the other points noted above).

Error! Reference source not found. provides approximate adjustment factors to scale energy from an ambient of 25°C to an ambient of 32°C. These factors are based on the analysis of actual data on the 30 models described earlier.

Table 9: Approximate Ambient Temperature Correction Factors (from 25^{o}C to 32^{o}C)

Group	Expected ratio heat gain calc	Additional factor for COP	Expected overall energy factor 32C/25C
1	1.3	1.13	1.47
2	1.3	1.12	1.46
3	1.29	1.11	1.43
4	1.28	1.10	1.41
5T	1.28	1.07	1.37
5B	1.27	1.03	1.31
5S	1.25	1.04	1.30
6U	1.18	1.07	1.26
6C	1.18	1.07	1.26
7	1.18	1.08	1.27

Note: Actual heat gain factor should be calculated for each model and the additional COP factor applied to this value to give an overall energy factor for each model.

As noted previously, the energy correction for changes in internal temperature should be undertaken first before the ambient temperature correction is applied.

Finally, it is worth (re) emphasising that ‘corrections’ for the heat gain at different ambient temperatures will require the slope to be estimated for each product (as per the equation on Page17) and then multiplied by the additional factor for the COP change (noting that the COP factors in Table 9 are for a 7 degree rise in ambient temperature).

References

EES (2007), *Impact of Changes in AS/NZS4474.1-2007 on Energy Consumption*, E3 Report 2007/13, prepared by Energy Efficient Strategies for E3, October 2007, see http://www.energyrating.gov.au/wp-content/uploads/2011/02/200713-as-nzs4474-energy-impact.pdf

EES (2008), *Consultation Regulatory Impact Statement of proposed revisions to the method of test and energy labelling algorithms for household refrigerators and freezers*, prepared by Energy Efficient Strategies for E3, Report 2008/04, June 2008, see http://www.energyrating.gov.au/resources/program-publications/?viewPublicationID=345

EES (2011a), *Paper 1: Summary of New MEPS Levels for Refrigerator in the USA, prepared by Energy Efficient Strategies for DCCEE*, October 2011, see http://www.energyrating.gov.au/blog/resources/events-calendar/24102011/

EES (2011b), *Paper 2: Road Map for MEPS3 in Australia and NZ – Issues for Stakeholders in the Alignment with US MEPS 2014*, *prepared by Energy Efficient Strategies for DCCEE*, October 2011, see http://www.energyrating.gov.au/blog/resources/events-calendar/24102011/

US Code of Federal Regulations PART 430—ENERGY CONSERVATION PROGRAM FOR CONSUMER PRODUCTS. Available from US Government Printing Office http://www.gpoaccess.gov/cfr/ - search for 10CFR430.

Annex 1: Background Information on Test Methods

IEC Draft Test Methods

IEC 59M/22/NP: IEC 62552-1 Ed 1.0: Household refrigerating appliances – Characteristics and test methods - Part 1: General Requirements;

IEC 59M/23/NP: IEC 62552-2 Ed 1.0: Household refrigerating appliances – Characteristics and test methods – Part 2 – Performance Requirements;

IEC 59M/24/NP: IEC 62552-3 Ed 1.0: Household refrigerating appliances – Characteristics and test methods - Part 3: Energy Consumption and Volume.

These were approved a Committee Drafts in October 2011. Revised Committee Drafts are expected in January 2012.

Australian and New Zealand Standards

AS/NZS4474.1-2007 *Performance of household electrical appliances — Refrigerating appliances Part 1: Energy consumption and performance.*
Amendment 2 to Part 1 was published in March 2011.

AS/NZS4474.2-2009 *Performance of household electrical appliances — Refrigerating Appliances Part 2: Energy labelling and minimum energy performance standard requirements.*

Amendment 1 to Part 2 was published in March 2011.

Annex 2: Refrigeration Types/Groups in Australia

Group	Type and notes
1	Group 1: Refrigerator without a low temperature compartment, automatic defrost. Single door refrigerator (no freezer compartment, automatic defrost, usually cyclic).
2	Group 2: Refrigerator with or without an ice-making compartment, manual defrost. Single door refrigerator (with small internal sub-compartment for making ice cubes, manual defrost, usually small (bar fridge size) to 150 litres) (equivalent to European 1-star).
3	Group 3: Refrigerator with a short or long term frozen food compartment, manual defrost. Single door refrigerator (short term frozen food sub-compartment inside, manual defrost, can be small or large to 300 litres) (equivalent to European 2-star).
4	Group 4: Refrigerator-freezer, fresh food compartment is automatic defrost, freezer manual defrost ("partial automatic defrost"). Refrigerator /freezer (cyclic defrost fresh food, manual defrost freezer, separate door for freezer and fresh food. Cannot identify whether freezer is top or bottom, side by side configurations do not exist, almost zero sales in 2008, typically 200-450 litres) (equivalent to European 3 or 4 star) (has at least two doors, though rarely more than two doors).
5	Group 5: Since 2001 the Group 5 configurations (refrigerator-freezer) have been split into three sub-types.
5B	Group 5B: Refrigerator-freezer, both compartments automatic defrost (frost free), bottom mounted freezer. Refrigerator -freezer (frost free with bottom freezer, typically 300-600 litres, larger freezer) (equivalent to European 3 or 4 star) (has at least 2 doors, sometimes more than 2 doors).
5S	Group 5S: Refrigerator-freezer, both compartments automatic defrost (frost free), side by side configuration Refrigerator-freezer (frost-free with side by side configuration, typically 400-800 litres) (equivalent to European 3- or 4-star) (has at least two doors, sometimes more than two doors).
5T	Group 5T: Refrigerator-freezer, both compartments automatic defrost (frost free), not side by side configuration or bottom mounted freezer (ie top mounted freezer). Refrigerator /freezer (frost free with top freezer, typically 200-550 litres) (equivalent to European 3 or 4 star) (has at least two doors, sometimes more than two doors).
6U	Group 6U: Separate vertical freezer, manual defrost. Vertical freezer - manual defrost.
6C	Group 6C: Separate chest freezer, all defrost types. Chest Freezer (all products are manual defrost, but technically could be frost free)
7	Group 7: Separate vertical freezer, automatic defrost (frost free). Vertical Freezer - frost free.