Benchmarking of Refrigerator-Freezers and Freezers among China, the United Kingdom and Canada

by

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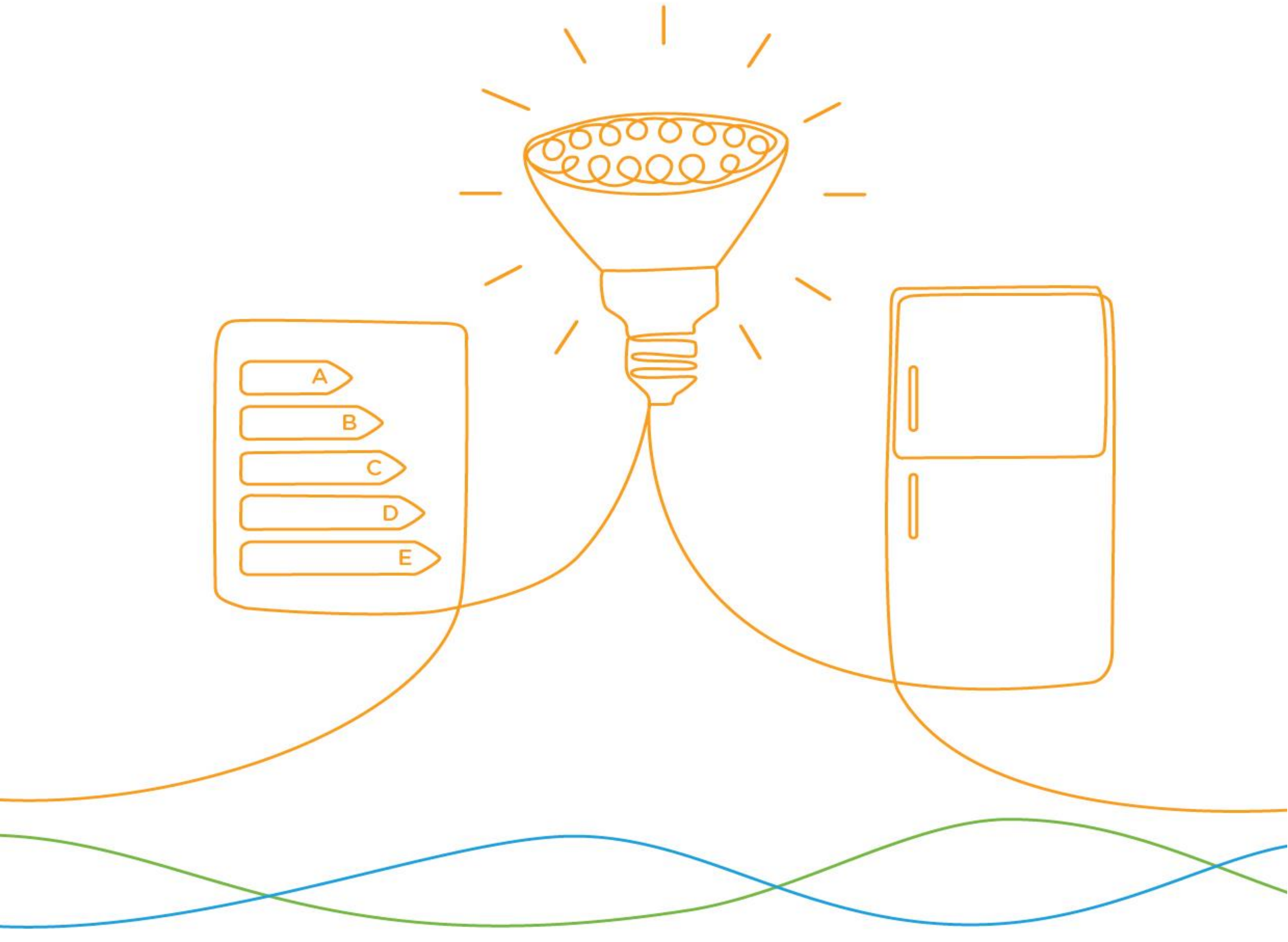

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Abstract

Refrigerated appliance types and models vary considerably among countries and so do the performance evaluation methods and required performance levels; these differences make direct performance comparisons across economies difficult. This report analyzes the differences in test conditions and in the evaluation of the base energy consumption[1] (BEC) formula that defines the base for calculating the MEPS and tier levels for labeling in each county's regulations. The report also provides a method for comparing the allowable maximum daily energy consumption per unit of adjusted volume for China, the UK and Canada on a common basis for household refrigerator-freezers and freezers. Differences among test methods currently being used in each economy include: ambient temperature, internal temperature, loading, inclusion/exclusion of defrost cycle, use of anti-condensation heaters and usage adjustment factor. Considering refrigerator-freezers on a common basis, base energy consumption (MEPS) is lowest for the UK and China and higher for Canada. Considering labels, the UK A+++ level has lower kWh/day than China Grade 1, which is lower than Canada ENERGY STAR. Similar results are found for freezers. A proposed new measure of efficiency is defined and utilized to compare the actual implied efficiency levels of the current MEPS and other performance grade levels across these economies, considering the variability of efficiency levels with total volume of the appliance. This proposed new measure is technology independent, implying that it applies to any combination of compartment dimensions, internal temperatures and features built into the product and has no bias related to compartment volume. This measure also permits applying specific objectives such as allowing setting much higher performance requirements for larger volume appliances in order to more tightly limit the electrical consumption per household.

[1] Base energy consumption = maximum allowable 24 hour consumption obtained from formulae provided in each country's regulations.

Introduction

Refrigerators, refrigerator-freezers, and freezers available in different countries can vary considerably by size, configuration, power input voltage and frequency, etc. Several countries or regions have developed test methods for measuring the performance and efficiency of these products, and some countries have adopted their own controlled temperature, ambient operating temperature, and unique minimum performance levels or labeling bin values. Results of these different tests are difficult to compare directly.

The comparison of performance of refrigerated appliances across various economies requires that the choices include models that are most common, have comparable functionality, and can be compared on an equivalent performance basis, i.e. operating under equivalent ambient and loading conditions and the daily consumption calculated on a comparable basis. The results of such performance comparisons can provide insight into the regulated levels of energy efficiency requirements, as well as the efficiencies of products available in these markets.

Benchmarking of appliances in different economies also requires a thorough review of the test methods used in each in order to define a method for making adjustments so as to make the individual test results directly comparable. Applying the adjustments provides a means for rating the efficiency in each economy against one another, revealing the actual differences on a common basis.

This study compares test methods and calculations used to rate the energy consumption of selected products among China, the UK and Canada. These countries were selected in order to facilitate the process of comparing appliance test methods, minimum efficiency performance standards (MEPS) and efficiency level classes for labeling. Since Canada and the US have harmonized test methods and performance levels, and the UK has adopted the EU regulations regarding appliance labeling, the results of this report can be considered to be representative of:

China,
Canada (and the USA) and
the UK (and the EU).

China's refrigerated appliance benchmarking is important at this particular time, since China's manufacturing base and market for refrigerators for local use are some of the largest in the world, and are expanding at a fast pace.

Figure 1   Number of Refrigerators and Freezers in use and Country Populations (2008)

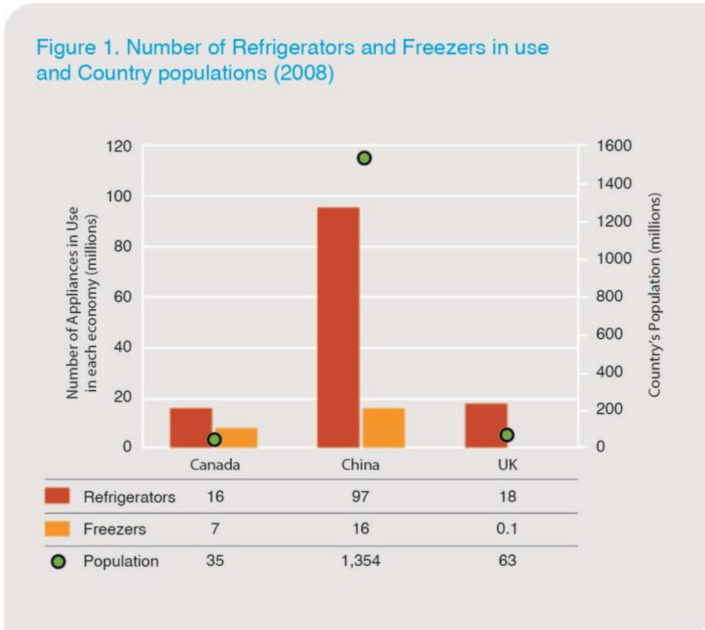


Figure 1. Number of Refrigerators and Freezers in use and Country populations (2008)

As can be seen on Figure 1[2], China's number of products in use far exceeds the numbers for the other two economies. "Refrigerators" on Figure 1 represent the number of refrigerators and refrigerator-freezers. The performance of refrigerated appliances has been improving steadily in China since the introduction of minimum energy performance standards (MEPS) and labeling according to a set of five Tier levels (Tier 1 being the most efficient). The vast majority of available models qualify for the two most efficient levels, Tier 1 and Tier 2 (as can be seen in Figure 2 for refrigerator-freezers and Figure 3 for freezers). CNIS is in the process of updating the test standards, the MEPS and the tier levels (Class limits) for labeling.

Figure 2   China Refrigerator-Freezers Energy Efficiency Level Distribution from 2009 to 2011 by Model Type

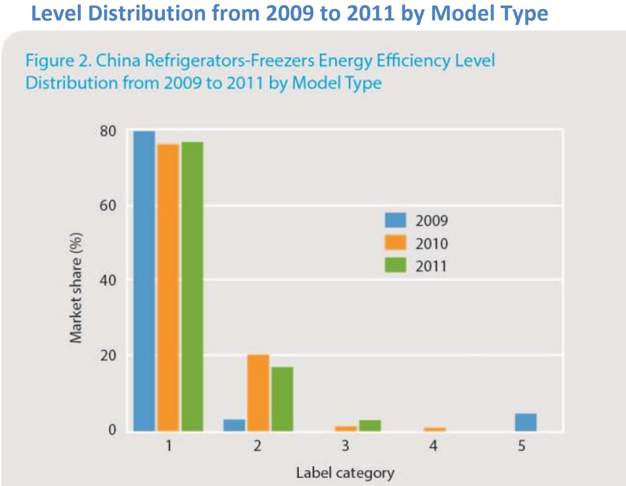


Figure 2. China Refrigerators-Freezers Energy Efficiency Level Distribution from 2009 to 2011 by Model Type

Figure 3   China Freezers Energy Efficiency Level Distribution from 2009 to 2011 by Model Type

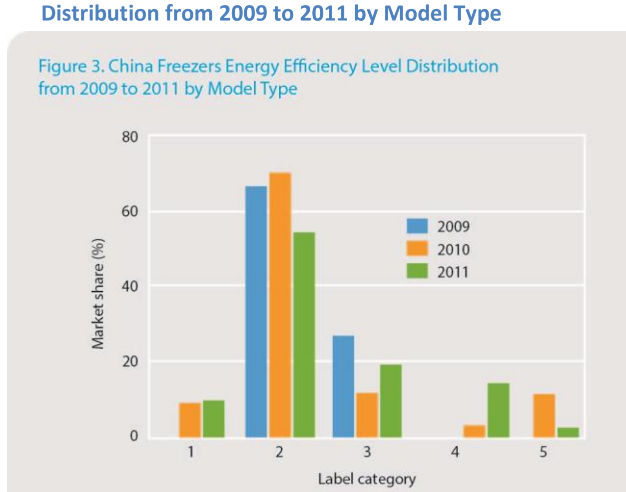


Figure 3. China Freezers Energy Efficiency Level Distribution from 2009 to 2011 by Model Type

[2] IEA 4E Mapping Documents for Canada, China, and the UK

Overview of Methodology

In order to fairly compare products from different economies, several steps are required:

1) Select product types that are sufficiently similar. For refrigerator-freezers, this includes consideration of the number and placement of compartments and size.
2) Consider differences in test conditions. Develop adjustment factors to convert from one country's set of test conditions to those of other countries.
3) Compare variations in sets of ratings (e.g., comparison or endorsement labels) and regulations (e.g., minimum energy performance standards (MEPS)).

Selection of product types for benchmarking

The first step in the benchmarking process is to define the common characteristics of the most popular appliances and to identify the product types that are included in each economy. In China, there are 7 types of refrigerated appliances for domestic use, which have been classified as follows:

Type 1 - Refrigerator only
Type 2 - Refrigerator with a 1-star compartment*
Type 3 - Refrigerator with a 2-star compartment*
Type 4 - Refrigerator with a 3- star compartment*
Type 5 - Refrigerator-Freezer with a 3-star compartment
Type 6 - Frozen food holding cabinet (has very limited freezing capability)
Type 7 - Freezer (with a specific food freezing capability)

* The temperature in the freezer compartment is –6°C in one-star models, –12°C in two-star models, and not higher than –18°C in three-star models.

The most popular types of refrigerated appliances available for sale in China have been highlighted above. The main technical difference between Type 4 (Refrigerators) and Type 5 (Refrigerator-freezers) is the amount of cooling capacity: Type 4 has sufficient cooling capacity to keep frozen food frozen, but not enough to freeze food introduced into the frozen food compartment at room temperature within a day or less. Type 5 is specifically designed with sufficient cooling capacity to freeze a pre-specified amount of food from room temperature in less than 24 hours.

A random sample of models representing about 1/3 of the models available in China indicated the following characteristics:

Appliance Type #	Number of Samples
1 – All-refrigerator	20
2 – Refrigerator with * compartment	3
3 - Refrigerator with ** compartment	4
4 - Refrigerator with *** compartment	99
5 - Refrigerator-Freezers	357
6- Frozen food holding cabinets	0

Appliance Type #	Number of Samples
7 - Freezers	81
Totals	744

Type 5 (Refrigerator-Freezers) were the most numerous. About 136 models claimed to have automatic defrost, 40 to be frost-free (implying forced air cooling in the freezer compartment) and 158 were claimed to be manual defrost. Most of the models were 2-door (219), with the balance (138) being 3-door.

Type 4 (Refrigerators) followed in popularity with 99 samples, having the following characteristics: about 7 had automatic defrost, 8 were frost-free and 11 were reported to be manual defrost. There was no indication of the defrost mechanism used in the remaining 72 models. A total of 3 models were reported to have 1 door, 51 models to have 2-doors, 37 to have 3-doors and 8 to have 4 doors.

Type 1 (All-Refrigerator) were rather rare with a total sample size of 20 models. Only one had automatic defrost, 9 had manual and the balance (10) had no indication on the defrost mechanism.

Types 2 and 3 were the rarest by far. These are very small capacity refrigerators with freezer compartments under 14 liters in capacity, refrigerators with 1-star or 2-star freezer compartments and frozen food holding cabinets (not capable of freezing a significant amount of food from room temperature over 24 hrs).

Product Types 1, 2 and 3 were excluded from this analysis.

Type 7: freezers (not holding cabinets) with a certain minimum freezing capability (4 kg/100 l per day) were the most common. Chest freezers normally have natural convection air movement. Only one out of a sample of 4 upright freezers indicated that it was frost-free. All upright freezers were either manual defrost, or not specified.

1. Test Standards[3] Review

1.1. Test standards used to evaluate energy consumption and performance

The standards used for evaluating the performance of refrigerated domestic appliances in each economy are listed on Table 1. These standards may reference other standards listed within each standard (for example, addressing electrical safety). Each of 5 standards describes the test conditions, test methods and required calculations that establish the information provided in the product specifications sheet as well as the electrical energy consumption under pre-specified loading and operating conditions. Some of the standards (e.g., Canada's) provide a table listing the annual energy consumption limits by product type and also consumption limits for "high efficiency" units. Other standards (e.g., UK, China) address only the test conditions and reporting requirements. The European and International standards (EN, ISO and IEC) generally specify measuring and reporting certain

[3] In this report, the word 'standard' refers to *a document established by consensus and approved by a recognized body that provides for common and repeated use, rules, guidelines or characteristics for activities or their results* (e.g., GB/T 8059.1-1995, ISO 5155:1995, CSA C300, etc.)

performance characteristics (not necessarily related to energy consumption) such as ability to maintain required minimum temperatures under each temperature classification, transfer of odor from surfaces, shelf strength, etc. The Canadian standard does not deal with other performance characteristics included in the EU standards. A comparison of the product coverage or scope of each standard is presented in the following section. Labeling requirements, minimum levels of performance and verification requirements are normally addressed by the regulations of each country or economy.

Table 1 Standards used in each economy

Economy	Standard
China *These products are excluded from the Benchmarking because of the low volume of sales.	**GB/T 8059.1-1995** *Household Refrigerators* (non-equivalent to **ISO 7371:1995** *Household refrigerating appliances – Refrigerators*) **Scope:** all-refrigerator type of appliances (Type 1).
China	**GB/T 8059.2-1995** *Household refrigerating appliances - Refrigerator-freezers* (equivalent to **ISO 8187:1991** *Household refrigerating appliances -- Refrigerator-freezers -- Characteristics and test methods*) **Scope:** Refrigerator-freezers with one- two- or three-star compartments and no forced air cooling. (China Types 2, 3 and 4)
China	**GB/T 8059.3-1995** *Household refrigerating appliances – Freezers* (equivalent to **ISO 5155:1995** *Household refrigerating appliances - Frozen food storage cabinets and food freezers - Characteristics and test methods***)** **Scope:** freezers and frozen food holding cabinets (with virtually no freezing capability) (China Type 6)
China	**GB/T 8059.4-1993** *Household refrigerating appliances - frozen food storage cabinets and food freezers* (equivalent to **ISO 8561:1995** *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)* **Scope:** refrigerators, refrigerator- freezers with forced air cooling, upright freezers with forced-air cooling (Types 5 and 7)
UK	**EN 153:2005** *Methods of measuring energy consumption of electric mains operated household refrigerators, frozen food storage cabinets, food freezers and their combinations, together with associated characteristics.* This standard has been replaced by the following standard. (The only changes made are a small correction to the energy use calculation and test voltage, and removal of mechanical test requirements.) ***EN ISO 15502:2005*** *Household Refrigerating Appliances - Characteristics And Test Methods* (refrigerator freezers)
Canada	**C300:2008** *Energy performance and capacity of household refrigerators, refrigerator-freezers, freezers, and wine chillers*

1.2.Performance specifications covered by the various standards

A summary of performance criteria for which the individual standards define a measurement approach is presented on Table 2. There is a cultural difference in approach to regulations on energy efficiency between Canada and the UK/China. In Canada, the regulations cover primarily energy use and virtually no other performance factors. In the UK and China, refrigerated appliances are required to meet certain service levels as well as energy performance factors; hence the underlying testing requirements are different. The indication is that the pure market mechanism favored by the Canada and the US is rejected in Europe.

It will be noticed that the Chinese standards and the UK standards cover multiple performance features of the products, especially those specifications that would normally be published in the product specification sheet for each model, including energy consumption. On the other hand, the Canadian standard covers primarily dimensional and energy consumption characteristics. The Canadian standard has been harmonized with the US regulations which include the test method and performance levels. The UK has adopted the EU regulations4. Performance specifications are normally listed by the manufacturer of the product on the individual product's Specification Sheet. Certification Bodies normally check for compliance with all the performance specifications in the standard before issuing their certification approval of the product.

Table 2 Performance aspects covered by each standard

Performance specification	China ISO 8187 GB/T8059.2 1955	China ISO 5155 GB/T 8059.3 1996	China ISO 8561 GB/T 8059.4 1993	UK EN ISO 15502 2005	Canada CSA C300 2008
Scope	Ref-freezers	Freezers & frozen	Ref-freez Freezers	Ref., Ref-freez Freezers	Ref., Ref-freez Freezers
Materials, design	√	√	√	√	x
Req'd Characteristics	Not forced air circulation	Not forced air circulation	Forced air circulation	Forced or not forced air circulation	Forced or not forced air
Air tightness	√	√	√	√	x
Opening force	√	√	√	√	x
Durability of hinges	√	√	√	√	x
Mechanical strength	√	√	√	√	x
Storage temperatures	√	√	√	√	√
Surface condensation	√	√	√	√	x
Energy consumption	√	√	√	√	√
Maximum Allowable energy consumption	x	x	x	x	√†
Name of manufacturer/vendor	√	√	√	√	√
Model designation	√	√	√	√	√
Range of temperature or Class (SN,N,ST or T)	√	Only N and ST	√	√	Non-specific
Occupied space dimensions	√	√	√	√	x
If for built in applications,	√	√	√	√	x
Direction of door opening or if reversible	√	√	√	√	x
Ambient temperature limitation test	√	√	√	√	x

[4] See Section 4

Performance specification	China ISO 8187 GB/T8059.2 1955	China ISO 5155 GB/T 8059.3 1996	China ISO 8561 GB/T 8059.4 1993	UK EN ISO 15502 2005	Canada CSA C300 2008
Rated energy consumption	√	√	√	√	√
Percentage running time;	√	√	√	√	x
Ice making capacity;	√	x	√	√	x
Rated storage shelf area.	√	√	√	√	√
Rated storage volumes	√	√	√	√	√
Limits	x	x	x	x	included
Sampling Plan	x	x	x	††	†††
Temperature rise time	√	√	√	√	x
Freezing capacity	√	√	√	√	√ (freezers)
Final test report	p.31	p. 21	p. 29	p.47	p. 40
Ice making	√	x	√	√	x
Absence of odour and taste	√	√	√	Informative	x
Designation: class, type, volume, etc.	√	√	√	√	x
Marking	√	√	√	√	x
Technical Literature and Advertising claims	√	√	√	√	Used in set up of appliance
Instructions for use	√	√	√	√	√
Acoustical Noise	x	x	x	IEC60335-2-24	x
% running time	√	√	√	√	√
Conditions particular to certain countries			See Page 50	Informative	
Built-in Refrigerating appliances	√	√	√	√	x
Rated Characteristics and Control procedures				Informative	

√ Specification included in the Standard

X Not included in the Standard

†Maximum annual energy consumption limit tables by product type are presented (two columns at different levels are presented in this particular case). Adjustment factors are defined for calculating adjusted volume for use with the maximum allowable annual consumption limits.

†† To be within 15% of rating or three other samples are to be tested, and the mean of all four to be within 10% of rating (page 84). Applies to energy consumption, ice making, volume, shelf area, temperature rise time, storage temperatures and freezing capacity.

††† 95% confidence level, one-sided distribution (See Appendix B in C300 Standard)

The five standards listed above, in addition to assisting in the characterization of refrigerated appliances and measurement of their performance, are also used to measure the 24-hour energy consumption of the appliances. Under normal use, the ambient temperature of the room where the appliance is located changes, and the appliance doors are opened and closed. Both of these factors affect the daily energy consumption of a refrigerated appliance. In order to simplify the test procedure, most economies use test standards that do not call for door openings, but do require an increase in the ambient temperature above normal room temperature during the test in order to try and compensate for the fact that doors are not being opened during the test. More details are presented in Section 1.4.1. Because of variations in ambient temperature conditions required by different test standards, differences in the test results are expected when the same appliance is tested to different standards.

The main factors that impact the daily energy consumption of a particular appliance are: ambient temperature, fresh food and freezer compartment temperature settings, and food loading during the test. The details of the ambient conditions, settings, calculations and other factors are detailed in the accompanying Annex 1.

1.3. The role of Test Standards and of Regulations in the Benchmarking Process

Refrigerating appliances are unique among appliances because of the large variety of types, sizes and operating characteristics, which makes it a real challenge to evaluate their efficiency and performance and to compare them against each other or against a national minimum efficiency requirement. In order to meet this challenge, compliance requires two specific components: a repeatable test method under a specific set of conditions, and a reliable calculation method to determine what the minimum performance requirement is for that particular model (taking into account the type of appliance, its size, its temperature control claims, climate zone, special features etc.). The first component, the test method, is important to ensure reliable, accurate, repeatable test results for the measured 24-hour actual consumption of the particular model under test. The second component, the calculated base energy consumption (BEC) of the product, is important in order to provide the correct interpretation of the regulation in place in an economy, which essentially specifies that an appliance of a particular type, size, operating temperature, ice-making capability, etc. must consume less than a certain (calculated) amount of electricity during a 24 hour period. The comparison between the actual measured daily consumption and the calculated limit set by the regulation establishes not only whether the product complies with the minimum requirement, but also, if it does comply, it determines the appropriate Class Level (1 to 5 in China or Class C to A+++ in the UK) for the product label.

When different economies use the same test method and operating conditions to measure the 24-hour consumption of refrigerated appliances, the direct comparison of performance across economies is straightforward and simple. When different test methods or testing conditions are used, the comparison across economies becomes much more complicated because the measured consumption results will differ and will not line up with the regulatory requirements that determine the MEPS in the country.

Section 1.4 summarizes the test conditions and points out the differences in the test methods currently being used in the UK, China and Canada to measure the 24-hour energy consumption. Section 1.5 summarizes the calculation of the BEC in each economy.

1.4. Test conditions specified in Test Standards

The main objective of this section is to compare differences among the test methods used in order to determine what adjustments would have to be made in test results if the same appliances were tested in each economy. This is a necessary step in the benchmarking process. An overall observation is that all the test procedures are very similar in terms of the types of measurements made, calculations needed and the way that test results are interpreted and used. However, there are some differences in the calculations made of the BEC which do impact the results. The various factors that result in some differences in results are discussed in more detail below.

The five standards in Table 1 are the set used for evaluating the performance and 24-hour energy consumption of refrigerator-freezers and freezers in countries under the scope of this study. The detailed test conditions are presented for each economy in Annex 1. Because of the current unavailability of English versions of the Chinese standards, the ISO standards (as indicated in Table 1) that were used originally for the development of the Chinese standards were used, and the critical test conditions were checked and updated according to the Chinese version of the corresponding ISO standard.

The applied voltage is an important characteristic to consider in the comparison of test conditions. Appliances for use in North America are designed for use at 115 V and 60Hz, while appliances for use in China and in the UK are rated at 220V and 50 Hz. The electrical and electronic components for appliances destined for North American markets will typically be different than those appliances destined to the European or Chinese markets because of the different voltage and frequency of the power supply. This situation may change in the near future as inverter units that may be capable of operating over a wider range of supply voltages and frequencies are introduced into the market. Table 3 summarizes the main test conditions that affect the 24-hour energy consumption measurement.

Table 3 Summary of test conditions affecting 24-hour consumption measurement for five test standards

Standard: **Condition:**	**CHINA GB/T8059.2 Refrigerator-freezers not Forced air**	**CHINA GB/T8059.3 Chest Freezers**	**CHINA GB/T8059.4 Refrigerator-freezers Forced air**	**UK EN ISO 15502:2005**	**CANADA C300 - 08**
AMBIENT for Class SN,N,ST,T for 24-hr energy consumption	25 ± 0.5°C	25 ± 0.5°C (Only Class N and ST)	25 ± 0.5°C	25 ± 0.5°C	32.2 ± 0.6°C
AMBIENT for Class T (only for checking cabinet temperature control)	32 ± 0.5°C	32 ± 0.5°C	32 ± 0.5°C	32 ± 0.5°C	32.2 ± 0.6°C
Fresh food Compartment Temperatures	5°C	N/A	≤ 5°C	+5°C	all-refrigerator: 3.3°C Refr-Freezer:≤ 7.2ºC
Cellar Temperature	12°C	N/A	N/A	N/A	N/A
Freezer Compartment Temperature	-18 °C	-18 °C	Two -star -12°C Three-star-18°C	One star - 6°C Two -star -12°C Three-star-18°C Four-star -18°C	Basic Refrigerator: -9.4°C Refr-Freezer: -15°C
Anti-condensation heater	off	off	off	off	on and off, average the test results
Freezer Loading	Filled with as many packages as can be fitted into freezer*	For V<50 as many as possible; For 50<V≤100: 40 kg/100 L; For V>100 : 25 kg/100 L*	For V<50 as many as possible; For 50<V≤100: 40 kg/100 L; For V>100: 25 kg/100 L*	Filled with as many packages as can be fitted into freezer*	May use weighted thermocouples or 75% of max capacity load
Energy consumed during defrost cycle	Not covered	Not covered	Not covered	Covered (in Clause 16.6)	Defrost component included (6 different defrost methods)
Energy consumption during defrost period	Not covered	Not covered	Not covered	Not covered	Defrost cycle and cooling cycle measured and apportioned to 24 hr period
How to calculate 24-hour energy consumption at required temp.	Test to measure energy cons. at two settings and interpolate	Test to measure energy cons at two settings and interpolate	Test to measure energy cons at two settings and interpolate	Test to measure energy cons at two settings and interpolate	Test to measure energy cons at two settings and interpolate
"Usage Factor" based on appliance type. (Used in calculation of 24-hr	Not included in the Standard	Not included in the Standard	Not included in the Standard	Not included in the Standard	K= 0.7 (Chest Freezers) K= 0.85 (Upright

Standard: Condition:	CHINA GB/T8059.2 Refrigerator-freezers not Forced air	CHINA GB/T8059.3 Chest Freezers	CHINA GB/T8059.4 Refrigerator-freezers Forced air	UK EN ISO 15502:2005	CANADA C300 - 08
consumption)					freezers) K= 1.0 (refr.-freezers)
Thermal Adjustment Factor	Not included in the Standard	Not included in the Standard	Not included in the Standard	Not included in the Standard	Included in the Standard: Refrigerator-freezers: 1.63 Freezers: 1.73
Error limit	Within 15% of claim	Within 10% of claim	Within 15% of claim	If higher than 15% of claim, test 3 more. Mean value needs to be ≤ 10% higher than rated value to pass.	Use one-sided confidence limit
Max cellar temp	12C		N/A		

* For V < 50 L, as many packages as possible, consistent with the storage plan but leaving space to accommodate the light load

Some of the variations in the ambient temperature required for the 24-hr consumption tests are associated with the intent to compensate for testing the appliances without opening doors, as well as for differences in assumed average room ambient temperatures across various economies. In Canada, the ambient temperature during the energy consumption test is 32.2°C, while in the UK and China it is 25.0°C.

The main variations in test conditions between China and Canada are related to: differences in supply voltage and frequency; difference in controlled temperature settings; difference in ambient temperature; use/no-use of the anti-sweat heater; consideration of type of defrost control used in the calculation of 24-hour energy use; and two factors: “usage factor” and “adjustment factor” that are used in the Canadian standard. The usage factor is intended to adjust the 24-hour consumption downwards because the 24-hour consumption for chest and upright freezers has been seen as being much higher than observed under actual use (with door openings and in normal, not elevated room temperatures). The thermal adjustment factor is similar in structure to the UK and China standards but uses different temperature values and is part of the standard itself, not part of the regulation.

The differences in test conditions between China and the UK are very small: the most salient one is the difference in loading of packages into the freezer compartment for the 24-hour consumption test.

Freezer Loading in China and the UK/EU Standards

The loading required for refrigerator-freezers and freezers in both China and the UK are similar for all appliances, except for chest freezers and refrigerator-freezers that are frost-free. For these types of products, the UK requires a full load in the freezer compartment, while China requires:

- a full load in freezer compartments with freezer Volume (V) under 50L;
- 40 kg/100 L freezer load for 50<V≤ 100;
- 25 kg/100 L freezer load for V>100

The load packages are defined in the same way in China and in the UK as follows:

Dimensions (mm)	Mass (g)
25 x 50 x 100	125
50 x 100 x 100	500
50 x 100 x 200	1000

The composition of the packages used in China and in the UK is as follows:

230 g of oxyethylmethylcellulose

764.2 g of water

5 g sodium chloride

0.8 g of 6-chloro-m-cresol

The freezing temperature of this mixture is - 1°C, corresponding to the characteristics of lean beef, with a density of 1000 kg/ m^3.

Freezer Loading in the Canadian Standard

The boxes used for loading of freezer compartments in Canada and in the US are designed to have the characteristics of frozen vegetables. The dimension and composition of the packages are:

Sealed boxes, with dimensions of 130 × 100 × 40 mm. The packages are filled to a density of 560 ± 80 kg/m^3 with hardwood sawdust that has been water-soaked. Alternatively, an equivalent package of frozen food, such as chopped spinach, may be used. The loading required for the test is 75% of full capacity.

The effect of different loads on the 24-hour consumption measurement can vary with the type of refrigerator-freezer or freezer, but the variation of consumption between partly and fully loaded is expected to be small. The difference in consumption between fully loaded and unloaded chest freezers was reported to be 3% lower consumption for unloaded; for upright freezers, the difference in consumption was 20% higher for the unloaded condition/1/. It should be noted that product designs and operating regimes are different now and so values quoted in this (1977) reference may no longer be representative of current product behavior.

Anti-condensation heaters: Some appliances are equipped with anti-condensation systems that include electric heaters and in some cases, refrigerant plumbing on the condenser side of the refrigerant system installed under the exterior surface to heat parts of the exterior of the appliance. In the UK and China standards, the electric anti-condensation heaters are to be off during the energy consumption test. In the Canadian standard, the energy consumption test is to be done once with the anti-condensation heaters on and once with the heaters off and the 24-hour energy consumption test results averaged. Some manufacturers provide a switch to control the heaters as needed during very humid conditions. Others use heat from the refrigeration system directly to heat the surfaces prone to produce surface condensation and thus avoid using additional electrical energy.

Important Observation: *Since the control of surface condensation is an important performance factor and can potentially consume a significant amount of extra energy, if ignored during testing, it could result in a higher appliance energy consumption in the field due to the use of electric anti-condensation* *heaters. If the energy requirement of these heaters were to be considered during product testing, this requirement might motivate consideration of design changes away from using electric heating and incorporating more efficient means of controlling condensation such as thermal breaks, refrigerant piping carrying warm gas, more thermal insulation, etc.*

To summarize, the test conditions required for China, the UK (and the EU) and Canada (and the US) that vary from one another are tabulated in Table 4. They include differences in test voltage, ambient temperature, controlled temperature, loading of compartments and defrost heater setting.

Table 4 Main Differences in Test Conditions Across Economies

Differences in test conditions among standards	China	UK	Canada
Test Voltage	230 V 50 Hz	230 V 50 Hz	120 V 60 Hz
Ambient temperature	25°C	25°C	32.2°C
Controlled temperatures	Fresh food: 5°C, Two-star freezer: -12°C, Three-star freezer: -18°C, Freezers only: -18°C	Fresh food: 5°C, Two-star freezer: -12°C, Three-star freezer: -18°C, Freezers only: -18°C	Fresh food ≤ 7.2°C, Freezer: -9.4°C (basic refrigerators, excluded for this analysis), -15°C(refrigerator-freezers), -17.8°C (freezers only)
Loading: Refrigerator-Freezers not frost-free	Fresh Food compartment: no load is used Freezer compartment: Full load is used	Fresh Food compartment : no load is used Freezer compartment: Full load is used	Refr-freezers with manual or semi auto defrost, use full load of packages.
Loading: Refrigerator-Freezers frost-free	For < 50 L, as many as possible less space for light load; For 50<V≤ 100: 40 kg/100 L For V>100 : 25 kg/100 L	Freezer compartment: Full load is used	Use no load in freezer compartment
Loading; Chest Freezers	For < 50 L, as many as possible less space for light load; For 50<V≤ 100: 40 kg/100 L For V>100 : 25 kg/100 L	Filled with as many packages as can be fitted into freezer	Freezers over 14.2 L, 75% loaded, or unloaded using weighted thermocouples
Loading: Upright Freezers	Freezer compartment: Full load is used	Filled with as many packages as can be fitted into freezer	Freezers over 14.2 L, 75% loaded, or unloaded when using weighted thermocouples.
Status of anti-condensation heaters during 24-hour energy consumption test	Heaters off	Heaters off	Test with heaters on and again with heaters off, average the results.

A review of the literature was conducted to try and determine the impact of certain variations in test conditions on the measured daily energy consumption of refrigerators and freezers /1/[5]. The main observations are described below.

1.4.1. Ambient Temperature

Ambient test temperature turns out to be a very sensitive test parameter because it affects directly the coefficient of performance of the refrigeration system, as higher ambient greatly reduces the efficiency of the refrigeration cycle. Tests conducted in 1977 (when refrigerator and freezer consumption was

[5] The reference is from 1977; refrigerator technology has advanced since then and thus estimates of impact on energy consumption may have changed.

much higher than today) at two different ambient temperatures on particular models of refrigerator-freezers and freezers were carried out at 23.9°C and at 32.2°C. The reported increases in consumption were as indicated on Table 5 /1/:

Table 5 Effect of increasing ambient temperature on energy consumption over 24-hour period

Ambient Temperature / Type of product	23.9°C, Closed Door Energy Consumption (kWh in 24 hr)	32.2°C, Closed Door Energy Consumption (kWh in 24 hr)	Increase for ΔT of 8.3 C degrees (kWh in 24 hr)	Increase for ΔT of 8.3 C degrees %	Increase for ΔT of 7.2 C degrees (25°C to 32.2°C) %	Percent Increase per Degree K
Automatic defrost refrigerator-freezer	4.80	6.53	1.73	36%	31%	4.3%
Manual defrost refrigerator	2.86	3.94	1.08	38%	33%	4.6%
Upright freezer	4.70	5.78	1.08	22%	19%	2.6%
Chest Freezer	2.14	3.05	0.91	42%	36%	5.0%

It was concluded that the increase in consumption with increasing ambient temperature is large and can vary considerably from one appliance type to the next, depending on the actual design and application of the refrigeration system. The difference in ambient temperature used in North America and in China/UK is (32.2°C – 25.0°C =) 7.2 C degrees. If we linearly adjust the above observations to represent an increase of 7.2 C degrees rather than 8.3 C degrees, the increase in consumption would be as indicated in Table 5, columns 6 and 7. This is only an estimate. The increase is expected to be non-linear with increasing ambient temperature, and is likely to vary from one model to the next depending on the refrigeration system design. More recent work[6] indicated that the impact of increasing the ambient temperature on energy consumption ranged between 2.8% and 3.4% per degree K for freezer compartments and between 1.4% and 2.1 % per degree K for fresh food compartments.

1.4.2. Controlled Temperatures

Reference /1/ reported observations of 24-hour energy consumption at two particular operating conditions: the maximum and minimum acceptable temperatures, assuming that the fresh food section had to be within the range of 0°C and 4.0°C, and the freezer section had to be below -12°C. From a plot of test results at the same ambient temperature, doors closed under various controlled temperature settings in the fresh food compartment, results are as shown in Table 6 for operation in an ambient of 32.2°C with empty refrigerators.

[6] Summary Overall Mapping and benchmarking Approach to the Analysis of Domestic refrigerated Appliances – Appendix 1- IEA4E 2012

Table 6 Energy consumption in 24 hrs at maximum and minimum acceptable compartment temperatures

	Minimum setting of 0°C (kWh)	Maximum setting of +4°C (kWh)	Difference in 24-hr consumption (%)
Automatic defrost refrigerator	6.5	5.0	26%
Manual defrost refrigerator	3.9	3.2	17%

Most currently available refrigerator-freezer designs in Canada and in the UK control the temperature of the freezer compartment directly, while the temperature of the fresh food compartment is determined by an adjustable, limited thermal link between compartments. New designs with individual active temperature controls for each of the compartments are becoming available in Australia and China. Therefore for most of the available models, it may not be possible to adjust the controls to achieve specific individual temperatures in each compartment. The level of control varies among designs. Refrigerators are normally operated somewhere between the two control extremes in order to achieve the desired combination of temperatures in the fresh food and freezer compartments.

1.4.3. Compartment loading

The effects of freezer compartment loading on the 24-hour energy consumption may differ widely from one type of refrigerator-freezer or freezer to another, with no way of predicting or forecasting the effects. A loading effect has been reported /1/ from measurements on refrigerator-freezers and freezers with manual and automatic defrost. For refrigerator-freezers, loading produced a minimal effect on the manual defrost refrigerator-freezer, but an increase in energy consumption of the automatic defrost unit (with forced air circulation). For an upright and a chest freezer, the results are shown in Table 7.

Table 7 Freezer Energy Consumption in 24 hrs.

	Loaded (kWh)	Unloaded (kWh)	% Difference
Upright freezer (forced air)	3.86	4.70	20
Chest Freezer (no forced air)	2.21	2.14	-3

The difference in energy consumption between a loaded and unloaded chest freezer is not significant, since the measured energy consumption can vary by ± 5%, and the variation from one sample to another (of the same model) can be as high as 10%. Several factors can affect the 24-hour energy consumption such as differences in the behavior of the appliance's temperature control system which can affect the length of compressor cycles. Short-cycling tends to reduce efficiency and increase energy use. Long cycles may overcool the load and also result in higher consumption. It can be concluded that appliances need to be loaded (or unloaded) in a similar fashion in order to compare 24-hour consumption. There is no reliable formula for predicting the effects of loading on the 24-hour energy consumption. For this reason, no adjustment can be made for differences in loading.

1.4.4. Door openings

None of the standards reviewed in this study include opening the doors during the 24-hour energy consumption test. However, the somewhat elevated ambient temperature during this test is intended to compensate somewhat for the fact that doors are not opened during the test.

1.5. Calculation of the Base Energy Consumption

In China and in the UK (as well as in the EU), once the test results for a particular product are obtained, a test report is normally prepared summarizing the findings, including the 24 hour energy consumption ($EC_{24\text{-}hr}$) and measurement of compartment volumes. The next step in the evaluation of performance involves applying the local economy's regulatory requirements to the product, which consists of calculating the base energy consumption (maximum allowable 24 hour consumption obtained from the formula provided in the regulations). The formula used for the evaluation is unique to the category of the appliance under consideration, taking into account the configuration of compartments, compartment temperature, defrost methods, presence of through-the-door ice-makers, temperature class, built-in type, etc. The result of the calculation is compared against the actual measured 24-hour consumption (or the value declared in the Product Specification Sheet) and the result establishes whether or not the product meets the MEPS and also the grade level that can be used on the energy label for the product.

In Canada, the refrigerator standard itself contains not only the test method for measuring the 24-hour energy consumption ($EC_{24\text{-}hr}$) and compartment volumes, but also the procedure for calculating the base energy consumption. Although the form of the formula to calculate the base energy consumption is similar to the form used in China and the UK, the parameters and adjustments are different, resulting in variations in results across economies. The measured annual consumption is compared against the calculated base energy consumption for the corresponding class and volume to ensure that it is below the maximum permitted level. The measured consumption is then applied to the label. The label contains not only the annual energy consumption for that particular model, but also the range of consumption for all other products in the same category.

It is clear that there are differences not only in the test method for measuring the 24-hr energy consumption across the three economies, but also in the way that the base energy consumption level is calculated for each category in each economy. For the purpose of benchmarking, it is important to evaluate on a common basis the actual 24-hr consumption. The base energy consumption calculation in all economies serves the purpose of comparing "apples with apples" within each economy, in other words, base energy consumption permits the regulators to compare products of various sizes within a category and to set minimum levels and grade levels according to their own criteria. The criteria usually consider eliminating from the market the highest consuming models and labeling the lowest consuming models with the highest grade level. However, there is no uniformity of criteria, targets, methodology or any obvious attempt to harmonize grade levels across economies. In the following sections, the formulation of the standard (or base) energy calculation in each economy will be described.

1.5.1. Base Energy Consumption Equation: China

In China, the base energy consumption for each class of appliance is defined as the minimum performance level that an appliance must meet according to the regulation GB 12021 – 2008/2/.

The base energy calculation is done on the basis of the 24-hour consumption. The base energy consumption (E_{base}) for China is defined as follows:

$$E_{base} = (M \times V_{adj} + N + CH) \times SR / 365 \quad \text{……………………………………(1)}$$

where:

M and N are unique linear equation parameters for each appliance type,

V_{adj} = Adjusted Volume

CH is an adjustment factor (50 kWh/year) for refrigerated appliances with a chill compartment with a storage volume of at least 15 liters (this is the same as in the EU regulations)

SR is an adjustment= 1.10 for refrigerators with a volume ≤ 100 liters and for refrigerators with a volume > 400 liters and penetration type ice-making function; SR = 1 for others

The adjusted volume of a refrigerator is calculated according to the formula:

$$V_{adj} = \sum_{c=1}^{n} V_c \times F_c \times W_c \times CC \text{……………………………………………(2)}$$

where:

n = number of different types of compartments

V_C = measured storage volume of a specific type of compartment (Liters)

F_C = Constant, equal to 1.4 for forced air cooling or 1.0 for non-forced air

CC = Climate type correction coefficient, (= 1 for N or SN, =1.1 for ST and = 1.2 for climate type T)

$W_C = \left(\frac{25-T_c}{20}\right)$ where T_c is the compartment temperature

Weighting coefficients of different types of compartments are presented on Table 8.

Table 8 Weighting coefficients or thermal Adjustment Factors for Various Compartments – China and UK

Type of compartment:	Fresh food	cellar	chiller	One-star	Two-star	Three-star	Freezer
T_c (°C)	5	10	0	-6	-12	-18	-18
W_c	1.00	0.75	1.25	1.55	1.85	2.15	2.15

Substituting for V_{adj} in equation (1), the base energy consumption equation becomes:

China: $E_{base} = (M \times \sum_{c=1}^{n} V_c \times F_c \times W_c \times CC + N + CH) \times SR / 365$ ………….(3)

1.5.2. Base Energy Consumption Equation: UK and EU

In the UK, the base annual energy consumption (BAE_C) is a linear equation defined as follows/3/:

$BAE_C = V_{eq} \times M + N + CH$ ……………………………….……(4)

where:

V_{eq} is the equivalent volume of the appliance and

CH is an adjustment factor (50 kWh/year) for refrigerated appliances with a chill compartment with a storage volume of at least 15 liters (same as in China)

The values of M and N are given in Table 7 of the regulation

The equivalent volume V_{eq} is calculated as indicated in Annex VIII of the Regulation. The calculation involves the following components:

The formula for calculating the equivalent volume is:

$$V_{eq} = \left[\sum_{c=1}^{c=n} V_c \times \left(\frac{25-T_c}{20}\right) \times FF_c\right] \times CC \times BI \quad \text{…………………………(5)}$$

where:

n = the number of compartments

V_c = storage volume of the compartment

T_c = temperature of the compartment (s) as set out in Table 2 of the Regulation

$\left(\frac{25-T_c}{20}\right)$ is the thermodynamic factor as set in Table 5 in the Regulation

FF_c, CC and BI are volume correction factors that reflect the air movement in the particular compartment (forced or not forced), the climate class and whether the appliance is of the built-in type or not. (FF_c = 1.2 for forced air cooling, FFC= 1.0 for not forced air; CC =1 for climate class S or SN, CC= 1.1 for class ST and CC = 1.2 for class T; BI = 1.2 for built-ins under 58 cm wide, BI = 1.0 for not built in)

Note that the only difference between the set of parameters used in the UK and China is the value of the correction factor for forced air (F_C = 1.4 in China and FF_c = 1.2 in the UK)

Substituting for V_{eq} in equation (4), the base energy consumption is

UK: $BAE_C = \left[\sum_{c=1}^{c=n} V_c \times \left(\frac{25-T_c}{20}\right) \times FF_c\right] \times CC \times BI \times M + N + CH$ (kWh/year) ………….(6)

The weighting coefficients or thermal adjustment factors in the UK and in China are the same (see Table 8).

Important Observation: *The adjusted volume calculation has a very important role in adjusting the base energy calculation value according to the size of the appliance. Since the adjustment factors for forced air movement used in the calculation of adjusted volume are not the same between China and the UK, the base energy consumption levels will be different, with China being biased towards allowing higher energy consumption levels for the same unit. (China factor F_C = 1.4 vs. UK factor FF_C = 1.2)*

There are at least two ways this issue can be avoided: re-classify appliances according to forced air or no forced air, or apply a correction factor outside of the calculation of adjusted volume.

1.5.3. Base Energy Consumption Equation: Canada

As was indicated earlier, the Canadian C300 test method is similar to the ISO methods for refrigerator-freezers and freezers, with the differences indicated in Table 4. The standard itself contains both the method for evaluating the energy consumption per day *and* the base energy consumption /4/ (maximum allowable level required according to the regulation).

The base energy consumption limits are evaluated as follows:

The adjusted volume (AV) of refrigerator- freezers and freezers is defined as:

$$AV = V_{fresh\ food} + (V_{freezer} \times AF)$$

where:

$V_{fresh\ food}$ = volume of fresh food compartment

$V_{freezer}$ = volume of the freezer

AF = adjustment factor (dimensionless)

The Adjustment Factor is calculated as follows:

$$AF = \frac{(t_A - t_{FSR})}{(t_A - t_{FF})}$$

where:

t_A = ambient temperature in the test room = 32.2°C

t_{FSR} = standardized freezer compartment temperature, (°C)

t_{FF} = average fresh food compartment operating temperature, (°C) = 3.3 °C

The weighting coefficients or thermal adjustment factors for the various compartments are presented on Table 9.

Table 9 Weighting coefficients or thermal Adjustment Factors for Various Compartments - Canada

	All-Refrigerator and wine chillers (no freezer)	In Basic Refrigerator	In Refrigerator-Freezers	In Chest and Upright Freezers
T_{FSR} (°C)	+3.3	-9.4	-15	-17.8
Thermal Adjustment Factor	1.0	1.44	1.63	1.73

Because the ambient temperature and compartment temperatures are different in the Canadian standard compared to the China and UK standards, the adjustment factors on Table 9 are different from the adjustment factors used in China and in the UK, presented on Table 8.

The maximum annual energy consumption is defined by appliance type (for 22 different product types) by the formula:

$$AEC_{max} = M \times AV + N \qquad (7)$$

M and N are defined in CSA Standard C300, "Table 1", under Energy Consumption Limits, as the slope and y-intercept respectively of the linear equations that represent the limits. The only other factors applied in the calculation of the 24-hour energy consumption are the *thermal adjustment factor* and the usage factor (as described on Table 3). These adjustments are applied during the final calculation of the 24-hour energy consumption after performing the 24-hour test. Unlike the China and UK regulations, these adjustments are not in the regulatory formula of maximum allowable consumption calculation. However, the final effect of applying a correction to the 24-hr consumption or to the BEC calculation is similar in all economies. Having no local adjustments at all in the test standard itself could make it easier to get acceptance of the test method across more economies.

It can be seen that unlike the China and UK regulations, there are no apparent adjustment factors on the Canadian formula for the maximum annual energy consumption. In actual fact, there are adjustments that are made prior to this stage in the calculation. The first adjustment in the Canadian method is done by breaking down the classifications more finely than in China or in the UK, so that there is more flexibility for the Regulator to set maximum consumption levels. For example, appliances are sub-divided into compact units (under 219.5 litres), and normal-sized units; refrigerator-freezers are sub-classified as side-mounted, top-mounted and bottom mounted freezers, and also by type of defrost (manual, automatic, partial automatic, with or without through the door ice service, and combinations). It is interesting to note that whether or not forced air is used, no sub-classification is used. Nearly all refrigerator freezers in Canada are frost-free types, making use of forced air.

The methods for calculating the BEC used in the three economies are not ideal from the point of view of making the energy performance limits in the regulations technology neutral. For example, in lighting applications, the efficiency requirement can be defined in terms of lumens per Watt, for any lighting technology (incandescent, fluorescent, LED, etc.). Adjustments and classifications of appliances according to features and configurations tend to move the regulations further away from a technology neutral target.

1.5.4. Comparison of Base Energy Consumption Calculations

The adjustment factors currently being applied to the base energy calculations in each economy are listed on Table 10.

Table 10 Adjustment Factors used in the calculation of base energy consumption in each economy

	China	**UK**	**Canada**
M,N values	See Table 12	See Table 14	See Table 16
Adjusted Volume	Same formula	Same formula	Same formula, different temperatures
If Chill compartment > 15 L	Factor CH: add 50 kWh/ year to BAEC*	Factor CH: add 50 kWh/ year to BAEC	N/A
Volume of refrigerator ≤100L or with through the door ice maker and >400L	S_R Factor = 1.1		Compact appliances (<219.5 L and an overall height of less than 91.4 cm) are classified separately
Forced air factor	Fc = 1.4 for forced air, Fc= 1.0 for non-forced air	FF=1.2 for forced air FF=1.0 for non-forced air	Automatic defrost classified separately from manual or partial auto defrost
Climate correction coefficient	CC= 1 for class N	CC=1 for class S or SN	Not dealt with

	China	UK	Canada
	CC= 1.1 for class ST CC= 1.2 for class T	CC=1.1 for class ST CC=1.2 for class T	
Built-in factor	None	BI =1.2 for built-in BI=1.0 for not built-in	Not considered
Adjustment to 24-hour energy consumption for various classes related to energy usage	None	None	None (However, in the calculation of 24-hr. consumption after the test, the following factors are applied: K= 1.0 for refrigerators and refrigerator-freezers K = 0.85 for wine chillers K= 0.7 for chest freezers K= 0.85 for upright freezers)

*BAEC= base annual energy consumption

1.6. Base Energy Consumption Regulated Requirements

The sections below describe the maximum allowable energy consumption limits, and the energy efficiency index to provide the grade level of the appliance as per the labeling requirements, for each economy.

1.6.1. Base Energy Consumption Requirements: China

In China, the maximum allowable energy consumption formulae contain adjustment factors to account for particular variations within classes, as discussed earlier. The maximum allowable daily energy consumption levels by appliance type in China in 2009 are presented in Table 11.

Table 11 Maximum (daily) allowable values of energy consumption – China (GB 12021.2-2008) for application in 2009

Type	Category	Maximum Allowable Value of Energy Consumption (E_{max} in kW.h/24h)
1	Refrigerator without star compartments	$0.9 \times (0.221 \times V_{adj} + 233 + CH) \times S_r / 365$
2	Refrigerator with one- star compartments	$0.9 \times (0.611 \times V_{adj} + 181 + CH) \times S_r / 365$
3	Refrigerator with two-star compartments	$0.9 \times (0.428 \times V_{adj} + 233 + CH) \times S_r / 365$
4	Refrigerator with three-star compartments	$0.9 \times (0.624 \times V_{adj} + 223 + CH) \times S_r / 365$
5	Refrigerator-freezer	$0.8 \times (0.697 \times V_{adj} + 272 + CH) \times S_r / 365$
6	Frozen food storage cabinet	$0.9 \times (0.530 \times V_{adj} + 190 + CH) \times S_r / 365$
7	Food freezer	$0.9 \times (0.567 \times V_{adj} + 205 + CH) \times S_r / 365$

Note:

(1) For refrigerators that have variable temperature compartments with a volume of 15 litres or more and chill zone function, the value of CH is 50 kW.h. Otherwise the value of CH is zero.

(2) For refrigerators with a volume of less than or equal to 100L or for refrigerators with a volume greater than 400 L and penetration type ice-making function, the value of S_r is 1.10. Otherwise, the value of S_r is zero.

(3) Refrigerators that do not fall into any of the categories on Table 11 shall fall into the proximate category according to the design temperature of the compartment with the lowest temperature.

The upgraded maximum allowable daily energy consumption levels by appliance type in China in 2013 are presented in Table 12. Types 6 and 7 were not upgraded.

Table 12 Maximum (daily) allowable values of energy consumption – China (GB 12021.2-2008) for application in 2013

Type	Category	Maximum Allowable Value of Energy Consumption (E_{max} in kW.h/24h)
1	Refrigerator without star compartments	$0.8 \times (0.221 \times V_{adj} + 233 + CH) \times S_r / 365$
2	Refrigerator with one- star compartments	$0.8 \times (0.611 \times V_{adj} + 181 + CH) \times S_r / 365$
3	Refrigerator with two-star compartments	$0.8 \times (0.428 \times V_{adj} + 233 + CH) \times S_r / 365$
4	Refrigerator with three-star compartments	$0.8 \times (0.624 \times V_{adj} + 223 + CH) \times S_r / 365$
5	Refrigerator-freezer	$0.7 \times (0.697 \times V_{adj} + 272 + CH) \times S_r / 365$
6	Frozen food storage cabinet	$0.9 \times (0.530 \times V_{adj} + 190 + CH) \times S_r / 365$
7	Food freezer	$0.9 \times (0.567 \times V_{adj} + 205 + CH) \times S_r / 365$

The grade level of an appliance is determined by using the calculated Energy Efficiency Index.

The Energy Efficiency Index (η), defined as:

$$\eta = \frac{E_{test}}{E_{Base}} = \frac{E_{test}}{(M \times V_{adj} + N + CH) \times S_r / 365} \quad \text{..........................(8)}$$

where:

E_{test} is in kWh/ 24 hours

E_{Base} is obtained from Equation (3)

The energy efficiency grade of a product is obtained from Table 13

Table 13 Energy Efficiency Grade for appliances in China according to Type and EEI

Energy Efficiency Grade	Energy Efficiency Index η	
	Refrigerator-freezer	Other types (1, 2, 3, 4, 6, 7)
1	η ≤ 40%	η ≤ 50%
2	40%< η ≤ 50%	50%< η ≤ 60%
3	50%< η ≤ 60%	60%< η ≤ 70%
4	60%< η ≤ 70%	70%< η ≤ 80%
5	70%< η ≤ 80%	80%< η ≤ 90%

The label used in China provides the Grade level (1 to 5) of the appliance.

1.6.2. Base Energy Consumption Requirements: UK

Table 14 presents the values of M (slope) and N (intercept) of the equation that defines the base energy consumption in the UK/EU. The highlighted lines represent the product types that are of interest to the benchmarking process in this report. MEPS levels for the UK were set for 1999 to 2010, limiting sales of refrigerators and refrigerator-freezers only to levels A, B and C, and for Freezers to levels A, B, C, D and E[7]. As indicated below, for refrigerator-freezers and freezers after 2012, the only levels allowed to enter the market are A+ and above.

Table 14 Values of slope (M) and intercept (N) for maximum energy consumption of various appliance categories in the UK

Description of Appliance	Category UK/EU	M UK/EU	N UK/EU
Refrigerator with one or more fresh-food storage compartments	1	0.233	245
Refrigerator-cellar, Cellar and Wine Storage Appliances	2	0.233	245
Refrigerator with a 0-star compartment	3	0.233	245
Refrigerator with a one-star compartment	4	0.643	191
Refrigerator with a two-star compartment	5	0.450	245
Refrigerator with a three-star compartment	6	0.777	303
Refrigerator-freezer	7	0.777	303
Frozen food holding cabinet			
Upright freezer	8	0.539	315
Chest Freezer	9	0.472	286
Multi-use and other Refrigerating Appliances	10	Note 2	Note 2

Note: for Category 10 household refrigerating appliances the M and N values depend on the temperature and star rating of the compartment with the lowest storage temperature capable of being set by the end-user and maintained continuously according to the manufacturer's instructions.

From the Tables above, the values of M and N for China and the UK are quite different for the corresponding product types. The implication is that the base energy consumption for any particular type of product is unique to each economy, usually based on the availability of certain models in each particular market; the labeling class levels are also different.

In the UK (and in the EU), the Energy Efficiency Index (EEI) is calculated as a percent as follows:

$$\text{EEI} = \frac{AE_c}{BAE_c} \times 100 \quad \text{………………………………………………(9)}$$

where:

$AE_C = E_{24\,h} \times 365$ = measured annual energy consumption (kWh/year)

and from Equation (4),

BAE_C = base annual energy consumption = V_{eq} x M+ N+ CH

and V_{eq} = the equivalent volume of the refrigerating appliance (as defined in equation (5))

[7] IEA 4E Mapping and Benchmarking Domestic Cold Appliances – United Kingdom

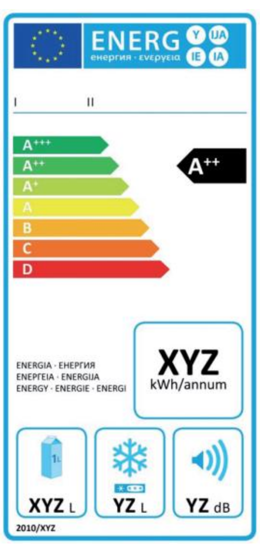
The values of M and N are given in Table 14 and the energy efficiency classes are calculated and presented in Table 15.

Table 15 Energy Efficiency Classes in the UK until 30 June 2014[8]

Energy Efficiency Class	Energy Efficiency Index
A^{+++} (most efficient)	EEI < 22
A^{++}	22 ≤ EEI < 33
A^{+}	33 ≤ EEI < **44**
A	**44** ≤ EEI < 55
B	55 ≤ EEI < 75
C	75 ≤ EEI < 95
D	95 ≤ EEI < 110
E	110 ≤ EEI < 125
F	125 ≤ EEI < 150
G (least efficient)	EEI > 150

The energy efficiency classes change from July 1, 2014 onwards only by the two highlighted numbers (44) changing to 42. In the UK, there are two different types of energy labels: one type used for household refrigerating appliances has colored bars corresponding to levels ranging from C to A+++ (for use on products rated at level C or above - see Figure 4). The other type of label has colored bars ranging from G to A+++ (for use on products rated below level C)[9]. The label is similar to Figure 4 but has three additional bars down to G.

Figure 4 Label for Household Refrigerating Appliances Classified in Energy Efficiency Classes A+++ to C



[8] COMMISSION DELEGATED REGULATION (EU) No 1060/2010 of 28 September 2010
[9] COMMISSION DELEGATED REGULATION (EU) No 1060/2010 of 28 September 2010, pages L 314/27 and L 314/30

In actual fact, in 2012, the minimum allowable performance level for refrigerator-freezers in the UK has been set to be under level A+, whereby the EEI must be below 44%. This level in fact becomes equivalent to the MEPS.

1.6.3. Base Energy Consumption Requirements: Canada

Presently, in Canada, Regulations reference C300-08 test procedure and the maximum energy consumption limits as indicated in the C300-08 "Table 1" ("Table 1" presented as Table 16 below for convenience). The M and N values for Canada (Table 16, column 2) (which are the slope and intercept respectively of each linear equation describing maximum annual energy consumption as a function of total adjusted volume), cover the annual energy consumption limit for each of the 22 categories of appliances, nearly half of which are "compact" appliances. The third column presents values of M and N that define the annual energy consumption limits for energy efficient appliances (associated with the ENERGYSTAR voluntary labeling program).

Table 16 Maximum energy consumption limits (kWh/year) currently in effect in Canada (extracted from C300-08)

Product Type	Energy Consumption limits (kWh/year)	Energy Consumption limits for high efficiency units (kWh/year)
1 - Refrigerators and refrigerator-freezers with semi-automatic or manual defrost	0.31 AV + 248.4	0.264 AV + 211.4
2 - Refrigerator-freezers with partial automatic defrost	0.31 AV + 248.4	0.264 AV + 211.4
3 - • Refrigerator-freezers with automatic defrost and top-mounted freezer without through-the-door ice service • All-refrigerators with automatic defrost	0.35 AV + 276	0.30 AV + 234.6
4 - Refrigerator-freezers with automatic defrost and side-mounted freezer without through-the-door ice service	0.17 AV + 507.5	0.145 AV + 431.375
5 - Refrigerator-freezers with automatic defrost and bottom-mounted freezer without through-the-door ice service	0.16 AV + 459	0.14 AV + 390.15
5A - Refrigerator-freezers with automatic defrost and bottom-mounted freezer with through-the-door ice service	0.18 AV + 539	
6 - Refrigerator-freezers with automatic defrost and top-mounted freezer with through-the-door ice service	0.36 AV + 356	0.31 AV + 302.6
7 - Refrigerator-freezers with automatic defrost and side-mounted freezer with through-the-door ice service	0.36 AV + 406	0.306 AV + 345.1
8 - Upright freezers with manual defrost	0.27 AV + 258.3	0.243 AV + 232.47
9 - Upright freezers with automatic defrost	0.44 AV + 326.1	0.396 AV + 293.49
10 - Chest freezers and all other freezers	0.35 AV + 143.7	0.315 AV + 129.33
10A - Chest freezers with automatic defrost system	0.52 AV + 211.5	
11 - Compact refrigerators and refrigerator-freezers with semi-automatic or manual defrost	0.38 AV + 299	0.30 AV + 239.2
12 - Compact refrigerator-freezers with partial automatic defrost	0.25 AV + 398	0.20 AV + 318.4
13 • Compact refrigerator freezers with automatic defrost and top-mounted freezer • Compact all-refrigerators with automatic defrost	0.45 AV + 355	0.36 AV + 284
14 Compact refrigerator-freezers with automatic defrost and side-mounted freezer	0.27 AV + 501	0.22 AV + 400.8
15 - Compact refrigerator-freezers with automatic defrost and bottom-mounted freezer	0.46 AV + 367	0.37 AV + 293.4
16 - Compact upright freezers with manual defrost	0.35 AV + 250.8	0.280 AV + 200.64
17 - Compact upright freezers with automatic defrost	0.40 AV + 391	0.32 AV + 312.8
18 - Compact chest freezers and all other compact freezers	0.37 AV + 152	0.30 AV + 121.6
19 - Wine chillers with manual defrost	0.48 AV + 267	
20 - Wine chillers with automatic defrost	0.61 AV + 344	

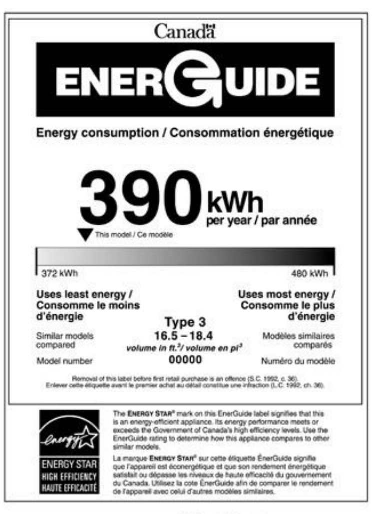
Notes:
(1) AV is the adjusted volume in litres as defined in CSA C 300:
(a) Clause 7.1 for refrigerators and refrigerator-freezers;
(b) Clause 7.2 for freezers; and
(c) Clause 7.3 for wine chillers.
(2) Calculated energy consumption limits shall be rounded to nearest kW•h.

Once again we notice that the values of M and N in the highlighted categories are different from the values of China and of the UK.

Canada's test method and maximum consumption limits are harmonized whenever possible and practical to those of the US. The US will be implementing a modified test procedure for domestic refrigerated appliances and more stringent energy consumption limits effective September 15, 2014[10]. The modified test procedure will cover 42 product types or classes (an increase from 22 current classes to 42 classes). The additional classes were introduced to account for the type of defrost system, ice-making capability, and type of unit (self-standing or built-in). Canada is planning to harmonize the test standard and maximum consumption levels and effective date with the US in the future through the next Amendment to the Canadian Energy Efficiency Regulations.

Although the test standards and maximum allowable consumption levels in Canada and in the US are presently harmonized, the labels used are different. A Canadian EnerGuide sample label is presented on Figure 5. The annual energy consumption of the product, as measured according to the C300-08 method, is printed on the label, along with a bar showing the full range of consumption of all other similar models, with an arrow indicating the particular product's annual consumption and its relative position on the range of similar products. If the product also meets the energy consumption limit (Table 16, column 3), then it can be labeled ENERGY STAR.

Figure 5 Canadian EnerGuide label for domestic refrigerated appliances



10 https://www.energystar.gov/products/specs/sites/products/files/ENERGY%20STAR%20Final%20Version%205.0%20Residential%20Refrigerators%20and%20Freezers%20Specification.pdf

To summarize, the application of the EEI in each economy is briefly described on Table 17.

Table 17 Summary of how EEI is used in each economy

	China	UK	Canada
Calculation of EEI	Used	Used	Not used
Form of rating or "grade"	Fraction < 0.99	22≤ % ≤ 110	kWh/ year for the product and the Range of kWh/year for the same type of appliance
Grade levels	1 to 5	A^{+++} to C (For domestic rerfrigerated appliances: A+ to A+++)	Meets minimum / High efficiency level
Must consume less than the base energy consumption	Yes	Yes	Yes

1.7. Concluding Comments on the Analysis of Test Standards, Base Energy Consumption Calculations and Class Levels across the Economies of interest

The process of benchmarking the performance of refrigerators and freezers across various economies requires that the energy consumption of products in each economy be tested to the same method, or that differences in test conditions be compensated for via reliable and consistent adjustments. A review of the test conditions used in China and in the UK is summarized in Table 3. It can be concluded that the test conditions for products in Chinese product classes 4, 5 and 7 are equivalent to the UK's test conditions for UK's product classes 6, 7, 8 and 9. There is a difference in the amount of food load required between the Chinese standards and the UK standard for the freezer compartment for larger volume refrigerator-freezers and freezers (China requires 40 kg/100 L of freezer load for 50<Volume≤ 100 L and 25 kg/100 L for Volume>100 L, while the UK requires filling the freezer). There is currently no method available to predict accurately the effects of the difference in loading of the freezer section on the 24-hour energy consumption measurement. Repetition of the measurement under the two different load levels would be required for each individual product in order to determine the effect on the 24-hour energy consumption measurement. In any case, the effect of variations in loading is expected to be very small.

The benchmarking of refrigerators between China and Canada is complicated by several major differences in test conditions, including ambient temperature, controlled temperatures, 24-hour energy consumption calculation, usage factor, use of anti-sweat heater and differences in freezer loading.

2. Development of correlations among test methods

If the same product were offered for sale in two economies that have different test methods, the cost of laboratory testing would be higher. From a manufacturer's perspective, developing a correlation between pairs of test methods used in different economies can potentially reduce the need to re-test the same model under each individual method and thus reduce the final cost of the product and help remove trade barriers. A single test method or a reliable correlation between test results using two different methods would also make it easier and cheaper for manufacturers to produce products with fewer variations needed in order to cover a larger market. From a consumer or policy perspective, developing a correlation makes it easier to compare the performance or efficiency of products sold in various economies. In the first case, the level of accuracy must be sufficient to meet regulatory requirements in each jurisdiction. In the second case, a statistically determined adjustment could provide a ranking of products by making up for differences resulting from variations in settings and test conditions required by each economy's test standard.

From the review of the test conditions in the 5 relevant standards for China, the UK and Canada, it appears that a good correlation can be developed between the Chinese standards and the UK standard for Chinese product types 4, 5 and 7. Section 1.4 indicated that there was virtually no difference in consumption between loaded or unloaded refrigerator-freezers and chest freezers. Only upright freezers appear to display a difference in consumption between full and no loading (See Table 7). The difference in consumption will likely be much smaller between a partial and full freezer load. Testing under these two conditions needs to be explored, especially since technologies may have improved since 1977.

The potential correlation between the Chinese standards and the Canadian standard is much more challenging because of large differences in required ambient temperature and controlled compartment temperatures, different usage of the anti-sweat heater and variation in freezer loading between standards. Developing an accurate correlation between a Chinese standard and the Canadian standard for a particular refrigerator-freezer model in order to avoid double-testing is not possible because of the following reasons:

- The appliance would have to be operated at the rated voltage and frequency;
- The highly non-linear behavior of compressor coefficient of performance with changing ambient temperature is difficult to predict and is likely to result in very large changes in consumption at higher ambient temperatures;
- Lower controlled temperature in the fresh food compartment: considering the limitations of individual temperature control of the fresh-food compartment, it is most likely that the freezer compartment temperature would have to be set at a much lower temperature in order to cool down the fresh food compartment just a few degrees, contributing to a much higher electrical consumption;
- The unpredictability of the impact of the anti-sweat heater on energy consumption;
- The potential impact of the difference in freezer load on the 24-hour energy consumption measurement;

- Variations in the way defrost energy enters into the 24-hour consumption calculation;
- Usage factors applied to the results in Canada that are not applied to the Chinese results.

For the purpose of benchmarking, however, we can make use of the following adjustments to the test results of a Type 5 refrigerator-freezer tested according to the Chinese standard GB/T8059.4 in order to predict what the 24-hour consumption under the Canadian test standard C300 would have been:

1. Assume that the rated voltage and frequency of the appliance is used for the test.

2. The factor associated with a change in ambient from 25°C to 32.2°C = increase in consumption of 31% (See Table 5)

3. Lower controlled temperature from 5°C to 3.3°C; according to Table 6, a change in controlled temperature of 4°C resulted in an increase in consumption of 26%, or 6.5% per C degree. Lowering the controlled temperature from 5°C to 3.3°C is estimated to increase consumption by (1.7 x 6.5% =) 11%

4. We assume that half the wattage associated with the anti-sweat heater, operated over 24 hours, can be added to the 24-hour energy consumption

5. We assume no impact on 24-hour energy consumption because of difference in freezer loading (for refrigerator-freezer) (See Section (1.4.3)

6. Assume that the defrost energy for an automatic defrost system is captured during the 24-hour measurement (no correction needed)

7. Usage factor: for refrigerator-freezers the adjustment factor in Canada is 1.0, therefore no adjustment is required.

The measured kWh/24-hr period for refrigerator-freezers according to standard GB/T8059.4 would have to be adjusted as follows:

China Refrigerator-freezers (forced air)

Consumption $_{C300}$ = (Consumption $_{GB/T8059.4}$ x 1.31 x 1.11 x 1 usage factor) + (½ x anti-sweat heater watts x 24/1,000)

= <u>about 45 to 50 % higher energy consumption</u> than using the Chinese standard, because of higher ambient and lower controlled temperature

If we go through the same process for chest freezers and upright freezers, the adjustments are as follows:

China refrigerator-freezers (not forced air)

Consumption $_{C300}$ = (Consumption $_{GB/T8059.2}$ x 1.31 x 1.11 x 1 usage factor) +

(½ x anti-sweat heater watts x 24/1,000)

= about <u>45 to 50% higher energy consumption</u> than using the Chinese standard because of higher ambient and lower controlled temperature

China Chest Freezers (not forced air circulation)

Consumption $_{C300}$ = (Consumption $_{GB/T8059.3}$ x 1.31 x 0.7 usage factor) + (½ x anti-sweat heater watts x 24/1,000)

= about <u>5 to 8% lower energy consumption</u> than using the Chinese standard because of the combined higher ambient temperature and lower usage factor of 0.7 (for chest freezers) in Canada. (Usage factor in China is assumed to be = 1).

China Upright Freezers (with forced air circulation)

Consumption $_{C300}$ = (Consumption $_{GB/T8059.4}$ x 1.31 x 0.85 usage factor) + (½ x anti-sweat heater watts x 24/1,000)

= about <u>11 to 15% higher energy consumption</u> than using the Chinese standard because of the combined higher ambient temperature and lower usage factor for upright freezers.

Cautionary Comments about the potential error in the above methodology

One must realize that there is a flaw in the method used for adjusting the freezer volume of a refrigerator-freezer in order to add the adjusted volume to the fresh food compartment volume, partly because of the heat transfer across the common wall between compartments, but also because the compartment adjustment related to the temperature difference across the compartment walls should be done according to the shell surface area exposed to the corresponding temperature differences. The method used in this report follows the traditional method using adjusted volume, rather than the more precise method using adjusted surface area. One of the main reasons that this method was not used in the study was that manufacturers are currently required to declare compartment volumes but not interior surface area of compartments that are exposed to the room ambient temperature. The common surface between compartments would be excluded, since the heat gains from the ambient air would not involve thermal transmission through the common wall between compartments. The expected error would be greater between units that have a large freezer and a small freezer, but having a similar calculated adjusted volume.

Appendix 2 deals with this issue offering a potential solution employing measured compartment surface area in order to calculate a more precise and comparable efficiency metric for all types of refrigerated domestic appliances. The new metric is used to determine the actual efficiency implications of the currently regulated levels of performance (MEPS and top Tiers across economies).

3. Results: Comparison of maximum allowable annual energy consumption levels among China, the UK/EU and Canada/US

The comparison of the maximum allowable consumption levels or efficiency levels of refrigerated products among various economies presents a number of challenges including the following:

- model variations: the maximum allowable energy consumption level for a refrigerator or freezer normally takes into account several factors that influence the amount of work that the appliance must do to maintain the conditioned compartments at the required temperatures, such as size, configuration, features such as through the door ice and water service, installation type, climate zones, etc.;
- variations in labeling: labeling grade levels corresponding to the relative efficiency of each brand name and model varies considerably across economies depending on arbitrary choices made by the local regulator.
- timing: the difference in timeframes when regulated minimum levels become effective can add to the level of complexity in the comparison.

The following summary provides a brief description of the applicable standards and labeling programs:

China

The energy labeling program has been in force in China since April, 2000; revisions were made in November, 2003 and most recently in May, 2009[11]. The regulation[12] contains the slope (M) and intercept (N) values and the formula for calculating the base energy consumption (BEC) by appliance type (MEPS) (see Table 11). A proposed change in the maximum energy performance standards (MEPS) to take effect four years later (May 2013) is shown in Table 12. The categories for determining the grade levels are shown on Table 13. In China, the BEC is used directly with the appliance adjusted volumes and other adjustments to evaluate the MEPS.

The United Kingdom

The UK follows the EU Commission Delegated Regulation No. 1060/2010 of 28 September 2010, supplementing the Directive 2010/30/EU of the European Parliament and of the Council with regard to energy labeling of household refrigerators. The UK has adopted the Euro zone regulation, including the maximum energy consumption as a function of volume shown in Table 14 and by efficiency class in Table 15, currently valid until June 2014. A minor revision to the levels of energy efficiency of two classes has also been published to follow July 1, 2014. Note that for the UK, the MEPS are represented by 44% of the EEI (or BEC) (starting in 2012). The MEPS levels are scheduled to be reduced to 42% in 2014.

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[11] IEA 4E Mapping Document - China
[12] See Table 4 in China Standard 12021.2-2008

Canada

Regulations for labeling of refrigerators and freezers were first implemented in Canada in 1978. Mandatory minimum energy performance levels started to be enforced in February 1995. Amendments were made to the regulations in 2001, 2006 and 2008, which included more stringent maximum energy consumption limits and the inclusion of additional configurations to the scope. The regulation currently in place covers products manufactured after Jan. 1, 2008. Table 16 contains the required maximum energy consumption limits for products for sale in Canada and the lower maximum consumption limits for more efficient products to be designated ENERGY STAR[13]. Canada's test standard C300-08 was updated in 2012 (only clarifications were made to the test method process), but the maximum consumption levels remained the same. Presently the new test procedure C300-12 is not mandatory because it is not used or referenced by the current Canadian Regulation. Plans are underway to update C300 (especially the Table of Maximum Energy Consumption Limits) before 2014 in order to harmonize it with the US announced requirements for September, 2014[14]. In Canada and in China, the BEC is used directly with the appliance adjusted volumes to evaluate the minimum energy performance levels.

In the following section the current minimum efficiency levels in each economy will be compared. The future levels will likely enter in effect the following dates:

China	2013
UK	July, 2014 (minor labeling grade level change for A+ from 0.44 to 0.42 of EEI)
Canada	Canada intends to harmonize maximum consumption limits with the US levels via the upcoming amendments to the Energy Efficiency Regulations, likely in 2014; the limits on Table 16 will be replaced with an updated set of values that will have somewhat more stringent maximum consumption levels and expanded range of product classifications: 42 instead of the present 22 (including wine coolers).

3.1. Process used for applying minimum energy efficiency and Labeling Grade levels

The initial steps in the process of determining the maximum allowable consumption level of a refrigerated appliance involve the following actions:

1. Identify the Appliance by Type (from a pre-defined set of types)

2. Test the appliance under a specified set of conditions in order to evaluate the 24-hour consumption and measure the volume of each compartment.

[13] Canadian Standard CSA C300-08
[14] http://www.gpo.gov/fdsys/pkg/CFR-2012-title10-vol3/pdf/CFR-2012-title10-vol3-sec430-32.pdf

3. Apply a formula provided in the regulation that calculates the *<u>base energy consumption</u>* *for that particular type of product using a linear equation of the form:*

Base Energy Consumption (BEC) = M x "adjusted volume" + N

where M = slope
and N= y- intercept

The adjusted volume is defined in terms of the sum of individual compartment volumes, adjusted according to individual compartment temperatures. The basic reason for this adjustment is an attempt to convert freezer compartments into equivalent (larger volume) fresh food compartments that would require the same amount of cooling but can be added to the actual fresh food compartment volume in order to obtain the total "adjusted volume" of a refrigerator-freezer or freezer. This type of adjustment is necessary because refrigerator-freezers have compartments of widely differing dimensions and proportions to the total actual volume, and the power consumption is related to the size of the refrigerated space (and thermal insulation level). Note that there are other "adjustment factors" applied to the adjusted volume calculations, as described earlier.

4. Calculate the base energy consumption at the particular adjusted volume of the model being appraised using the regulator's formula;

5. Finally, compare the calculated base energy consumption against the measured 24-hour consumption of the appliance. If the model's consumption exceeds the permissible level, then it is not approved for sale.

For example, the formula for China (2008) Type 5 refrigerator-freezers is:

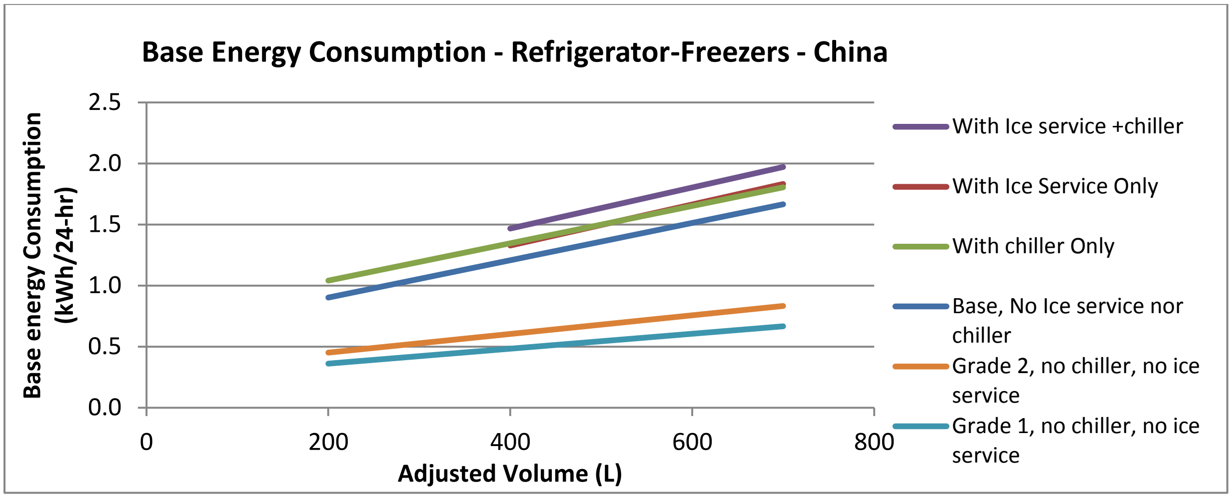
Maximum value of energy consumption = $0.8 \times (M \times V_{adj} + N + CH) \times S_r / 365$ .....(10)

Maximum value of energy consumption = $0.8 \times (0.697 \times V_{adj} + 272 + CH) \times S_r / 365$

The values of slope (M) and intercept (N) for Type 5 appliances are 0.697 and 272 respectively. CH and S_r are special factors that are built into the equation to allow slightly different limits for appliances with different features that do affect energy consumption, as explained in Table 10. This function has been plotted on Figure 6 for various configurations: a unit with no chiller (CH= 0) and no ice-service (S_r = 1) corresponds to the dark blue line, an ice service unit (S_r = 1.1) to the red line, a unit with chiller only (CH = 50) corresponds to the green, etc. On the same Figure 4 are also presented the two highest grade levels for refrigerator-freezers, Grade 1 and Grade 2 representing 40% and 50% of the Base level.

In order to apply the same formula to appliances over a range of volumes, a ratio of freezer volume to total volume was selected to be = 1/3. This ratio was used in all the calculations involving adjusted volume. Also note that on Figure 6 the Base Energy Consumption is plotted against *adjusted volume*.

Figure 6 Maximum allowable energy consumption for Type 5 Refrigerator-Freezers[15] - China



If we then plot the actual 24-hour *measured* energy consumption of any particular product of the same type along with its own adjusted volume on the same chart, the location of the point relative to the regulated level at the same adjusted volume, determines whether the model passes or fails the maximum 24-hour consumption allowed. If the point is above the line, the product does not comply. If it is below the line, the ratio of the products' actual measured value to the maximum allowable level determines the grade level or efficiency index, depending on the way the labeling scheme is designed.

The simple form of the linear formula that describes the regulation limits, allows regulators to apply simple "adjustments" by adding or multiplying factors to account for various features built into certain appliance models that affect energy consumption (as seen above for units with chillers and ice service). The only exception is with the application of the factor corresponding to the use of forced air, which is applied to the adjusted volume calculation (see Important Observation in section 1.5.2., for a discussion on the corresponding issues). Certain factors can be applied to the right side of the equation in order to adjust the overall limit for various purposes, as will be illustrated next.

Consider equation (10) for calculating the MEPS limit in China for a type 5 refrigerator-freezer,

- The right side has a multiplier of 0.8. The effect of this factor was to lower the maximum 24-hour consumption level by 20% from a previous (historic) setting of the level. The net effect is the linear lowering of the limit for all adjusted volumes.
- The factor CH = 50 kWh/year is applied only to refrigerator-freezers that have an adjustable temperature chilled zone larger than 15 L. The net effect is an increase in maximum allowed 24-hr consumption of 50 / 360 = 0.139 KWh per 24-hour period for all adjusted volumes (a straight shift up, parallel to the slanted line of the corresponding model on Figure 6).
- The factor S_r has a dual purpose:

[15] GB 12021.2-2008 Minimum Allowable Values of Energy Efficiency and Energy Efficiency Grades for Household Refrigerators (Summary) to be implemented in 2012

(a) for refrigerator-freezers with a volume greater than 400 L that have a through-the-door ice-service, a 10% increase in the limit is allowed by applying the factor S_r = 1.1 due to the fact that this feature results in approximately a 10% increase in 24-hr consumption.

(b) for small refrigerators of 100 L or less, the factor S_r = 1.1 is applied in order to allow these smaller products to have 10% higher energy consumption. The reason is that the relative interior surface area to volume ratio in a small refrigerator is much larger than in large refrigerators, so that on a per volume basis, very small refrigerators gain more heat from the room per unit volume and therefore consume more energy per unit volume than large refrigerators, and the regulated limit is thus increased to make this allowance.

(c) for all other situations, S_r = 1.0

3.2. Appliance Classifications vs. Adjustments

A review of how various economies handle the use of classifications and adjustment factors indicates that there are considerable variations in the way countries classify the products found in their respective markets. There are also indications that where certain appliance configurations or features are not that common in an economy, the application of certain adjustment factors are favored instead of new classifications by "Type" in order to include in the scope of the regulations the majority of available refrigerated products. Otherwise, many of these less common models would not be covered by the regulations and could lead to opportunities for low efficiency special models to unfairly compete against the regulated and complying models. One way to resolve this conflict is to try to make energy efficiency standards technology neutral, rather than technology driven (for example, by defining requirements that would eliminate the need for defined classes or configurations); this approach would most likely encourage manufacturers to apply technology improvements in order to improve the efficiency of their products rather than to restrict them to working within a set of specific configurations or classes that may lose relevance over time or in different economies.

The combination of *classification by Product Type* and *adjustments* for the models that have extra (energy consuming) features that consumers demand, are the main tools that regulators use currently to meet the requirements for flexibility, fairness and clarity of the regulations. Cooperation between regulators and industry in the structuring of efficiency levels over time normally leads towards the setting of efficiency targets that are achievable by manufacturers. This practice, developed over time, accommodates some level of creativity of manufacturers of these products as well as some of the consumers' demand for models that meet their requirements and desired energy savings levels.

The comparison of performance of products across economies and the amount of effort required to harmonize performance levels would be greatly simplified if a single test standard were adopted by the various economies, and if all adjustments and correction factors unique to each economy were applied directly to the test results. The comparison of performance levels (24-hour consumption test) among Canada, China and the UK requires the use of test results from similar tests, but carried out at different test conditions. Some countries adjust the 24-hr consumption, and others do not. They all apply their own unique BEC formula (or equivalent) which includes adjustment factors that determine the limits set in their economy by appliance type and features.

By listing the appliance types, configurations and features of interest relevant to China's benchmarking study on one table, one can see the common adjustment factors among the three Types (4, 5 and 7) that when applied to calculate the BEC, have a similar effect as classifying products into different sub-categories (parallel to what is being done in Canada and in the UK). Since both systems for setting performance limits result in a similar outcome, one cannot claim that one system is superior to the other. The disadvantage of both systems is that the sub-classification of appliances may impede creative manufacturers from implementing more efficient technologies within any one or more of the product sub-classifications.

Table 18 Features and adjustment factors by appliance class (China)

Appliance By Class Type (China)	**Configuration**	**Air movement F_C = 1.4 applied to compartment**	**Defrost**	**Through the door Ice service SR**	**With chilled compartment >15 L CH**
Type 4 - Refrigerators with 3-star compartment	1, 2 or 3 doors (bottom, top or side freezer)	Natural	Manual or semi-automatic		Add 50/365 kWh/day
		Forced 1.4	Automatic		
Type 5 Refrigerator-freezers	Bottom freezer (2-door, 3 door)	Natural	Manual or semi- automatic		Add 50/365 kWh/day
		Forced 1.4	automatic		
	Top freezer (2-door, 3 door)	Natural	Manual or semi- automatic		
		Forced 1.4	automatic		
	Side freezer (2-door, 3 door)	Forced 1.4	Automatic	No service With service 1.1	
Type 7 Freezers	Upright	Natural	Manual		
		Forced 1.4	Automatic		
	Chest	Natural	Manual		

Other factors that would require re-classification or adjustment factors are:

- *Climate Class* factors to be applied:

  CC=1 for class N (32ºC ambient)
  CC= 1.1 for class ST (38ºC ambient)
  CC= 1.2 for class T (43ºC ambient)

- *Size factor* to be applied to refrigerators under 100 L volume:

  Sr = 1.1

In the case for China, Table 18 would have to be completed for products in each Climate Class.

In Canada, there are currently 22 different types of appliances to cover the defrost method and air movement, configuration of compartments, etc. and there are no adjustments made to the BEC equation. Only one adjustment is made to the calculation of the product's 24-hr energy consumption (the usage factor). This increase in precision becomes more important as differences in efficiency between models are reduced and overall efficiencies improve over time. New appliance categories have been announced by the US for September 2014 which include 42 types or classes of refrigerator-freezers and freezers. The new categories are defined by the type of defrost system, ice-making capability, self-standing or built-in type of unit. It is interesting to note that unlike China, no specific types have been defined according to the climate zone or to the availability of a chill compartment.

In the remainder of this section, the normalization of the base energy consumption levels in each of the economies is developed.

Important Observations: *The value of a common test methodology including common ambient and test conditions is clearly most desirable from the point of view of comparing performance of refrigerated products. Standardizing the product classifications and harmonizing the regulations in terms of the format of the base energy consumption will remove the barriers to comparing regulatory requirement levels and would facilitate the approvals process; ultimately, it would reduce the cost of the products by avoiding repeated testing.*

3.3.Comparison of 24-hour base energy consumption of refrigerator-freezers across economies

In order to compare the MEPS levels in each economy against one another, it is necessary to use equivalent models (configuration, type of defrost control, similar type of air movement, features, and similar real volumes). As long as the test method used in each economy uses the same procedure and temperature settings and ambient temperature, the measured 24-hr energy consumption would be directly comparable. Any differences in test methods, temperature settings and ambient that would impact the 24-hr energy consumption of a product would have to be taken into account in order to adjust (or *normalize*) the comparison between BECs across economies. This issue will be reviewed for each economy before comparisons are made against the UK regulated levels.

3.3.1. UK (levels in effect from 20 Dec. 2011 until 30 June 2014)

The formula for calculating the base energy consumption for refrigerator-freezers in the UK is:

UK: $$BAE_C = \left[\sum_{c=1}^{c=n} V_c \times \left(\frac{25-T_c}{20}\right) \times FF_c\right] \times CC \times BI \text{ x M + N + CH} \quad \text{(kWh/year)} \quad \ldots\ldots\ldots\ldots(6)$$

For the purpose of benchmarking BEC levels, the following assumptions were made:

1. the refrigerator-freezer is a bottom freezer type,
2. not built-in, (BI = 1)
3. climate class S or SN, (CC = 1)
4. does not have through the door ice service

5. has forced air cooling (FF_C = 1.2)
6. the ratio of freezer volume to total volume was assumed to be 1/3.
7. the total appliance volume was assumed to be 420 L (fresh food and freezer volumes are 280 and 140 L respectively), which is near the middle of the volume range.
8. has no chill compartment (CH = 0)

The relevant volume adjustment factor (from Table 8) is 2.15. M and N for refrigerator freezers are 0.777 and 303 respectively.

Finally, the MEPS level requirement for 2012 limits sales to products reaching at least A+ level[16]. This level is equivalent to under 44% of the EEI. Note that the A+ level drops to 42% in 2014.

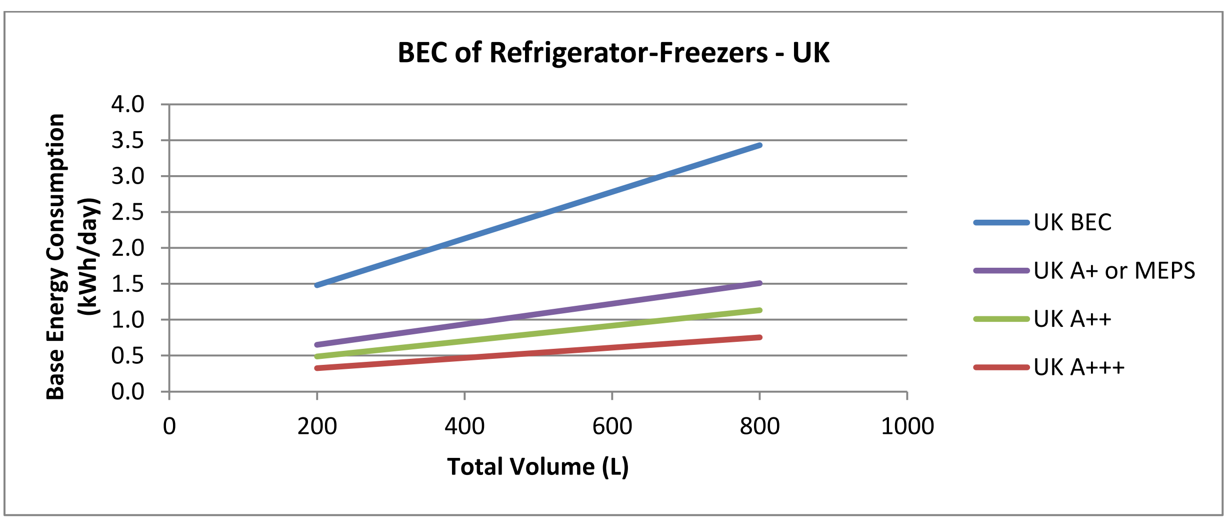
Substituting the appropriate values for the volumes and adjustments into equation (6), we calculate the base energy consumption:

$$BAE_C = \{280 + 2.15 \times 140 \times 1.2) \times 1 \times 1 \times 0.777 + 303 + 0 = 801.2 \text{ kWh/year or } 2.20 \text{ kWh/24-hrs.}$$

Therefore the MEPS level would be: $BAE_C \times 0.44$ = 352.5 kWh/year or 0.97 kWh/24-hrs.

The results of applying the formula to a range of appliance actual volumes from 200 to 800 L are presented graphically on Figure 7. The only allowable refrigerator performance levels are A+, A++ and A+++, since all units must be A+ or above in order to be allowed to be offered for sale. The reason for plotting against actual (rather than adjusted) volume is that the calculated adjusted volumes for refrigerator-freezers in the UK and China differ because of the forced air factor (= 1.4 in China and = 1.2 in the UK, both of which are applied to the adjusted volume calculation, as discussed earlier in Section 1.5.2). In Canada, refrigerator-freezers have their own category and forced air or not does not affect the calculation of BEC, so that no adjustment factor is used.

Figure 7 Base Energy Consumption of Refrigerator-Freezers for the UK



[16] IEA4E Mapping Document: Country: UK
http://mappingandbenchmarking.iea-4e.org/shared_files/315/download

3.3.2. China (values in effect from 2012 onwards)

The formula for calculating the base energy consumption for refrigerator-freezers in China is:

E_{base} = (M x$\sum_{c=1}^{n} V_c \times F_c \times W_c \times CC$ + N + CH) x SR / 365 ………….(3)

For comparing levels of base energy consumption in China, equivalent to the MEPS against the UK MEPS level, we make the same assumptions about the type of refrigerator-freezer and apply the corresponding adjustments for China as follows:

1. the refrigerator-freezer is a bottom freezer type,
2. not built-in, (not used in China)
3. climate class S or SN, (CC = 1, same as in UK)
4. does not have through the door ice service, (SR = 1, same as in UK)
5. has forced air cooling. (F_C = 1.4, not 1.2 as in the UK)
6. the ratio of freezer volume to total volume was assumed to be 1/3.
7. the total appliance volume was 420 L (fresh food and freezer volumes are 280 and 140 L respectively)
8. has no chill compartment (CH = 0)

The relevant volume adjustment factor W_C (from Table 8) is 2.15. M and N for refrigerator freezers are 0.697 and 272 respectively.

For the purpose of comparing the values used as assumptions for the calculation of the base energy consumption in the UK and in China, these are tabulated on Table 19.

Table 19 Tabulation of assumptions and values used in the calculation of BEC in the UK and in China

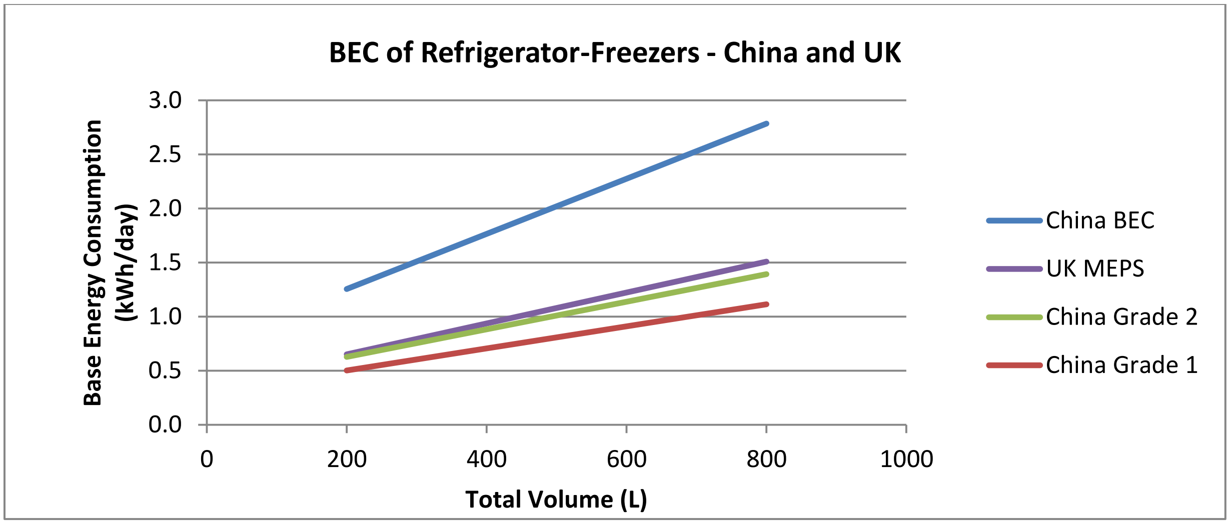
Assumptions	Values used according to assumptions made	
	UK	China
Configuration of Refrigerator-freezer	bottom freezer	bottom freezer
Not built-in	B = 1	(not used)
Climate Class S or SN	CC = 1	CC = 1
No through the door ice service	None	SR = 1
Forced-air cooling is used	FF_C = 1.2	F_C = 1.4
Ratio of freezer volume to total volume	1/3	
Total appliance Volume	420 L	420 L
Absence of Chill compartment	None	CH = 0
Volume Adjustment Factor	2.15 (see Table 8)	2.15 (see Table 8)
Values of M and N	0.777 and 303	0.697 and 272

Substituting the appropriate values for the volumes and adjustments into equation (3), we calculate the standard energy consumption:

E_{base} = {0.697 x (280 +2.15 x 140 x1.4) x 1 + 272} x 1 /365 = 2.08 kWh/ 24-hr

The results of applying the formula to a variety of appliance volumes are presented on Figure 8, along with a comparison of the UK level.

Figure 8 Base Energy Consumption for Refrigerator-Freezers for the UK and China



It is interesting to note that the M and N values are different for the UK and China. Also, the adjusted volume calculation in the UK uses a factor of 1.2 for forced air (automatic defrost) and China uses 1.4. The UK MEPS level is nearly equivalent to the China Grade 2 level of performance, with a slight difference in slope with appliance total volume. Since the test methods are essentially identical, the net effect of the differences in the regulated levels implies different grade ratings in each country.

3.3.3. Canada

In Canada's test method for refrigerators, refrigerator-freezers and freezers there are three major factors that are different from the China and UK test methods which affect the measured 24-hr. energy consumption:

1. ambient temperature
2. use factors
3. controlled temperature settings in compartments

First, the test method used in Canada calls for a higher ambient temperature (32.2°C) than in the UK and in China (25.0°C). The difference in ambient temperature requires more work to remove the heat from the compartments; the extra work is estimated to result in a 30% increase in electrical consumption, or 4.2% per degree C increase in ambient temperature[17]. (Let us call this factor an "ambient" factor of 1.3 for the purpose of comparison of base energy consumption levels between Canada and the UK).

Second, Canada also uses an adjustment factor "K" ("Use factor") (not used in the other economies) which is applied in the calculation and declaration of the 24-hr energy consumption. This factor is intended to reduce the consumption expected in practice with the lower number of door openings of freezers (compared to refrigerator-freezers) as follows[18]:

[17] "Freezer and Freezer Energy Consumption", ASHRAE Transactions, Vol. 83, No. 1, 1977
[18] CSA C300- Energy performance and capacity of household refrigerators, refrigerator-freezers, freezers, and wine chillers

The measured 24-hour energy consumption is to be adjusted by multiplying it by the following factors:

K= 1.0 for refrigerators and refrigerator-freezers
K = 0.85 for wine chillers
K= 0.7 for chest freezers
K= 0.85 for upright freezers

The above factors are used directly in the calculation of the 24-hr energy consumption for the declared values.

The effect of combining the higher ambient factor and the usage factor K results in the following adjustment made to each type of product (K x 1.3):

= 1.0 x 1.3 = 1.3 for refrigerators and refrigerator-freezers
= 0.85 x 1.3 = 1.105 for wine chillers
= 0.7 x 1.3 = 0.91 for chest freezers
= 0.85 x 1.3 = 1.105 for upright freezers

Third, because Canada uses different controlled cabinet temperatures, the adjustment factors used for the adjusted volume calculations differ from those for China and the EU. Please refer to Table 6.

In order to be able to compare the base energy requirement in Canada under equivalent test conditions, adjustments need to be made to the appliance's base energy measurement calculation as well as to the base energy consumption in the regulations.

Adjustments to the declared energy consumption

The higher ambient temperature has the effect of increasing the energy consumption by 30 %.
The use factor for refrigerator-freezers is 1, so there is no correction needed.
The controlled temperatures are:

	Fresh food	Freezer
China and UK	+ 5°C	-18°C
Canada	+ 3.3°C	-15°C

The temperature control function in a refrigerator-freezer normally acts directly on the compressor control to turn it on and off in order to control the freezer temperature; the fresh food temperature is dependent on the amount of cooling provided by the freezer (while the compressor is on or off), in a variety of ways (air openings to the freezer compartment that may be adjustable, secondary cooling coil, heat transfer through the common wall, etc.). Therefore it will be the difference in controlled freezer temperature that will determine the likely difference in consumption between different thermostat settings. From the ASHRAE paper/1/ it was estimated that an automatic defrost refrigerator-freezer consumes 2.6% more energy per C degree when the controlled temperature is lowered. Therefore it is estimated that testing Canadian refrigerator-freezers at a higher freezer temperature (by 3 C degrees) than in the UK and China is expected to decrease the consumption of Canadian refrigerator-freezers by a factor of 3 x 2.6 % = 7.8 %. The adjustment will be 1.078. This is only an approximation based on the assumption that for most currently available refrigerator-freezers the fresh food section temperature is dependent on the freezer temperature as only the freezer temperature is independently controlled; thus temperature in the fresh food section may also change as the freezer temperature control is adjusted. A few models having totally independent temperature controls in the fresh food and freezer sections are available. This is the reason the UK, China and Canada refrigerator test standards do the test twice at two different control settings and interpolate the results of each of the two tests to the target compartment temperatures.

Finally, the thermal adjustment factor used for the adjusted volume calculations in Canada is different than the UK factor, as shown on Tables 8 and 9 (1.63 Canada vs. 2.15 UK). Since we are adjusting the Canadian conditions to meet those of the UK, the volume adjustment factor for the UK will be used on the Canadian refrigerator-freezer E_{base} calculations.

To summarize:

The Canadian test method for measuring the annual or daily energy consumption, compared to the UK method, does the following:

1. Increases consumption by 1.3 X because of a higher ambient temperature
2. Does not change the consumption due to the "usage factor" for refrigerator-freezers
3. Decreases consumption by 1/1.078 because of the 3 C degree higher freezer temperature during the test than in the UK
4. Adjustment factor for volume is 2.15*

*The error introduced via the use of adjusted volume rather than adjusted surface area can be reduced if surface area of the compartment were being used.

When these adjustments are made to the regulatory base energy consumption of Canada, the level is expected to be on a similar basis, making the actual levels comparable.

The formula for maximum allowable AEC in Canada for refrigerator-freezers with bottom freezer is:

AEC = 0.16AV +459

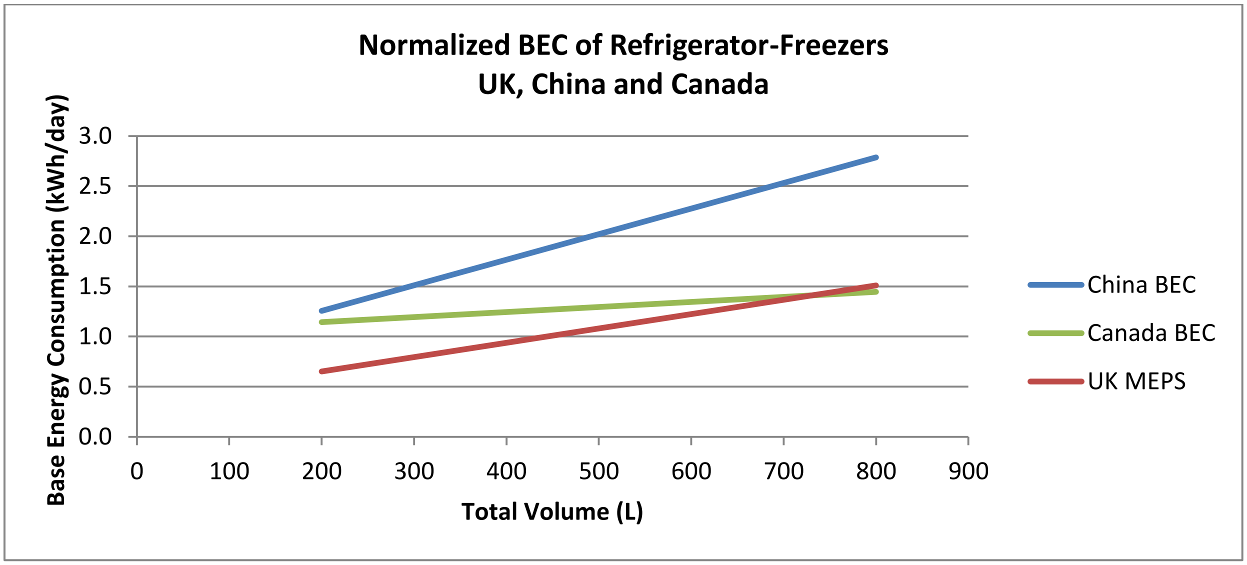
Next, we will adjust the AEC limit for a 420 L refrigerator freezer (FF compartment = 280 L and freezer compartment = 140 L) as follows:

1. We multiply the right side by 1/1.3 to compensate for the lower ambient used in the UK
2. No change due to the usage factor (=1)
3. Multiply the right side by 1.078 because of the lower freezer temperature in the UK
4. Calculate the adjusted volume according to the more severe UK conditions (2.15)

AEC ={ 0.16 (280 + 140 x 2.15) + 459 }x 1.078/1.3 = 457.7 kWh/year or 1.25 kWh/24-hr

The results of applying the formula to a variety of appliance <u>volumes</u> are presented on Figure 9 in the form of Base Energy Consumption (BEC) vs. Total Appliance Volume (not total adjusted volume) all normalized to UK conditions, along with a comparison of the UK and China levels. The BEC for China and for Canada are equivalent to the MEPS for the UK.

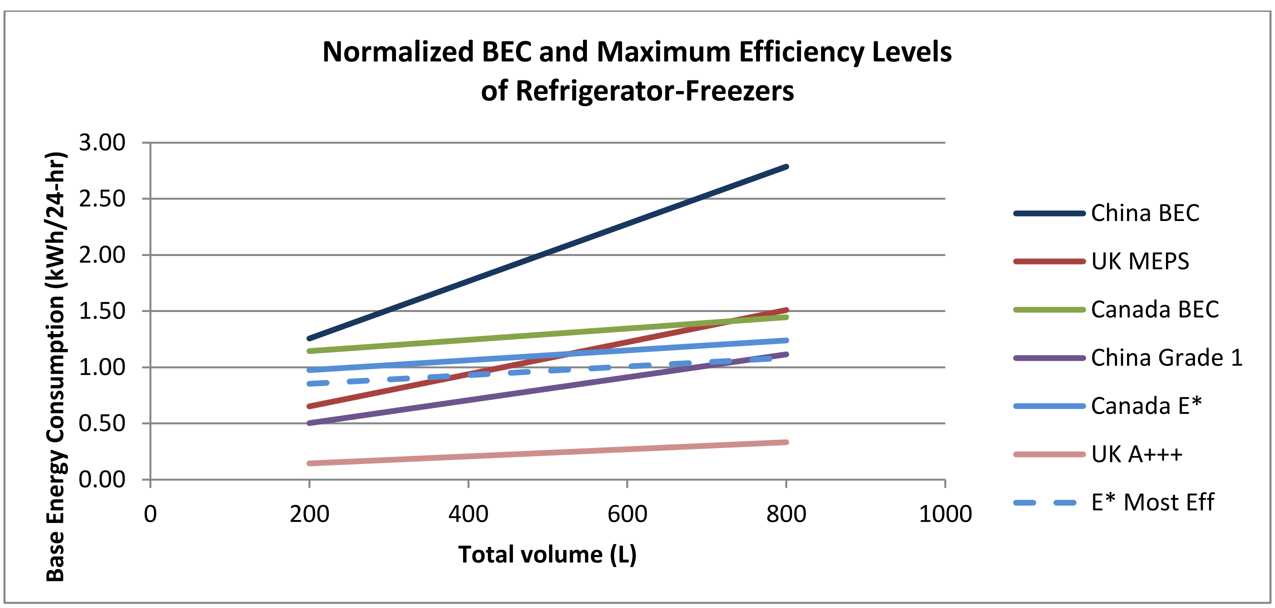
Figure 9 Base Energy Consumption for Refrigerator-Freezers for the UK, China and Canada



The BEC is used in China and in the UK to determine the grade level of the appliance, as described on Tables 13 and 15. In Canada, the values on Table 16, Column 3 establish the "High efficiency" levels, used for ENERGY STAR designation.

On Figure 10 are presented the China Grade Level 1, the UK Level A+++ and the ENERGY STAR level for US and Canada for refrigerator-freezers, all normalized to the UK conditions.

Figure 10 Normalized Base Energy Consumption or MEPS levels and Highest Efficiency level for Refrigerator-Freezers for the UK, China and Canada (UK conditions)



One more classification has been added to Figure 10 to illustrate the impact on consumption levels of a new program recently introduced into Canada called "ENERGY STAR Most Efficient 2013" in the April 11, 2013 edition of Canada's Economic Action Plan blog[19]. The announcement referred to the inclusion of domestic refrigerated appliances in the ENERGYSTAR Most Efficient Product Program was posted at the indicated site[20]. This program recognizes refrigerators and refrigerator-freezers that consume less energy than ENERGY STAR rated products meeting the ENERGY STAR Product Specification for Residential Refrigerators and Freezers Version 4.1 as indicated below:

- For total adjusted volume ≤ 49.6 cu ft, 12.5% lower consumption
- For total adjusted volume > 49.6 cu ft, consumption below 481 kWh per year

The designation "ENERGYSTAR Most Efficient 2014" is intended to be used on literature describing or promoting the product, but the product itself cannot be labeled with the "Most Efficient" designation. The graphic to be used is presented below in Figure 11.

Figure 11 ENERGYSTAR Most Efficient 2014

Figure 10 contains the dashed line which represents the energy consumption level for ENERGY STAR Most Efficient products, 12.5% below the ENERGY STAR level.

Please note that the BEC levels for China and Canada are representative of the MEPS for each country. In the UK, the BEC is multiplied by 0.44 to represent the MEPS (declared in 2012 until 2014, after which date the multiplication factor becomes 0.42). . In China, the highest grade (Level 1) must be below 40% of the BEC. In Canada, high efficiency models are rated only 15% below the BEC level. In the UK, the highest efficiency units rated A+++ must be below 22% of the BEC. Thus relative to the BEC, the UK has the most stringent requirement for Grade A+++, followed by China Grade 1 level and then by the ENERGY STAR level for Canada and the US.

3.3.4. Summary Observations on Refrigerator-Freezer MEPS levels and highest performance class levels in the three Economies.

At this point, it is useful to compare the regulated levels across the three economies by taking the simplest type of refrigerator-freezer in three sizes: small, medium and large volume, and calculating the normalized BEC and highest grade level energy consumption for each appliance. For this purpose, we picked a 200 L, 500L and 800 L appliance. For each of these, the BEC, the MEPS and the estimated consumption of the highest grade level were calculated. The results are presented in Table 20.

[19] http://actionplan.gc.ca/en/blog/energy-star-most-efficient-2013-identifying-best
[20] http://www.energystar.gov/ia/partners/downloads/ES_Refrigerators_Final_Most_Efficient_2013_Recognition_Criteria.pdf?1375-26fa

Table 20 Comparison across economies of normalized maximum daily consumption levels for BEC, MEPS and highest grade level for various refrigerator-freezer volumes

Economy	BEC			MEPS			Highest Grade		
Volume (L)	**200L**	**500 L**	**800 L**	**200L**	**500 L**	**800 L**	**200L**	**500 L**	**800 L**
Canada*	1.14	1.29	1.44	1.14	1.29	1.44	0.97	1.11	1.24
China	1.26	2.02	2.79	1.26	2.02	2.79	0.50	0.81	1.11
UK	1.48	2.46	3.43	0.65	1.08	1.51	0.33	0.54	0.75

* Considers ENERGY STAR levels in Canada for the highest grade

UK's MEPS levels require lower energy consumption than Canada's and much lower than China's levels for all product sizes. China's daily energy consumption for the highest grade level refrigerator-freezers is about 1.5 x higher than the UK's; it is also nearly half of the Canadian levels for small sizes, but about the same for large volumes. The Chinese consumption levels corresponding to the highest grade could be tightened, especially for the larger volumes in order to more closely match the levels in the UK.

3.4.Comparison of 24-hr base energy consumption of Freezers

In order to compare the regulated efficiency levels for freezers across economies, a similar analysis as above was carried out. For the purpose of benchmarking, the most common type of freezer was chosen: the chest freezer.

3.4.1. UK

The formula for calculating the base energy consumption for freezers in the UK is:

UK: $BAE_C = \left[\sum_{c=1}^{c=n} V_c \times \left(\frac{25-T_c}{20}\right) \times FF_c\right] \times CC \times BI \times M + N + CH$ (kWh/year) ………….(6)

The basic assumptions made for the purpose of benchmarking across economies were:

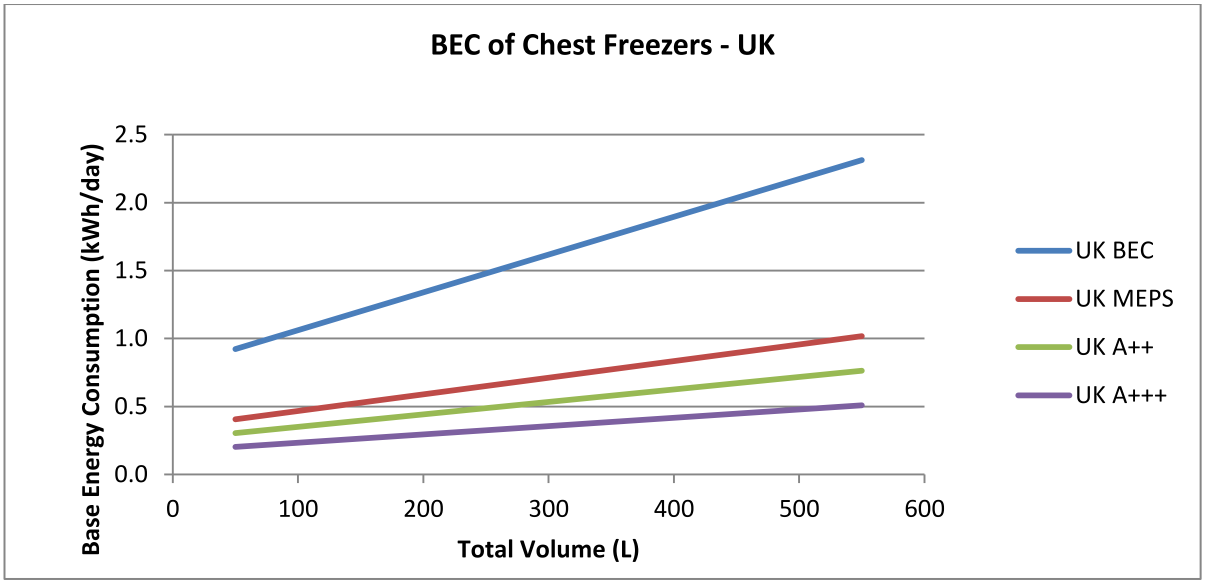
1. not built-in (BI=1)
2. climate class= ST (CC=1)
3. does not have through-the-door ice service
4. has no forced-air movement (FFC = 1.0)
5. there is 0 fresh food volume
6. the freezer volume was assumed to be 200 L
7. has no "chill compartment" (CH = 0)

The relevant volume adjustment factor (from Table 8) is 2.15. M and N for chest freezers are 0.472 and 286 respectively.

Substituting the appropriate values for the volumes and adjustments into equation (6), we calculate the base energy consumption:

BAEc = {0+2.15 x 200 x 1) x 1 x 1 x 0.472 +286 +0 = 489.0 kWh/year or 1.34 kWh/24-hrs, which we will call the Base Energy Consumption (BEC). The results of applying the formula to a range of appliance volumes ranging from 50 to 550 L are presented on Figure 11. The only allowable freezer performance levels are A+, A++ and A+++, since all units must be A+ or above in order to be allowed to be offered for sale. Once again, actual volumes are used instead of adjusted volumes because the adjusted volume calculations are different for units with forced air movement in the UK and China and for the normalized Canadian values.

Figure 12 Base Energy Consumption of Freezers for the UK and derived Grade Levels



There is no differentiation between compact and normal size freezers in the UK.

3.4.2. China

The formula for calculating the base energy consumption for freezers in China is:

E_{base} = (M x$\sum_{c=1}^{n} V_c \times F_c \times W_c \times CC$ + N + CH) x SR / 365 ………….(3)

For comparing levels of base energy consumption against the UK level, we make the same assumptions about the type of freezer and apply the corresponding adjustments for China as follows:

1. the freezer is a chest type, manual defrost
2. not built-in, (not used in China)
3. climate class S or SN, (CC = 1, same as in UK)
4. does not have through the door ice service, (SR = 1, same as in UK)
5. has convection cooling, not forced air (F_C = 1.0)
6. the total freezer volume was assumed to be 200 L (compact is 219 L and below in Canada)
7. Has no chill compartment (CH = 0)

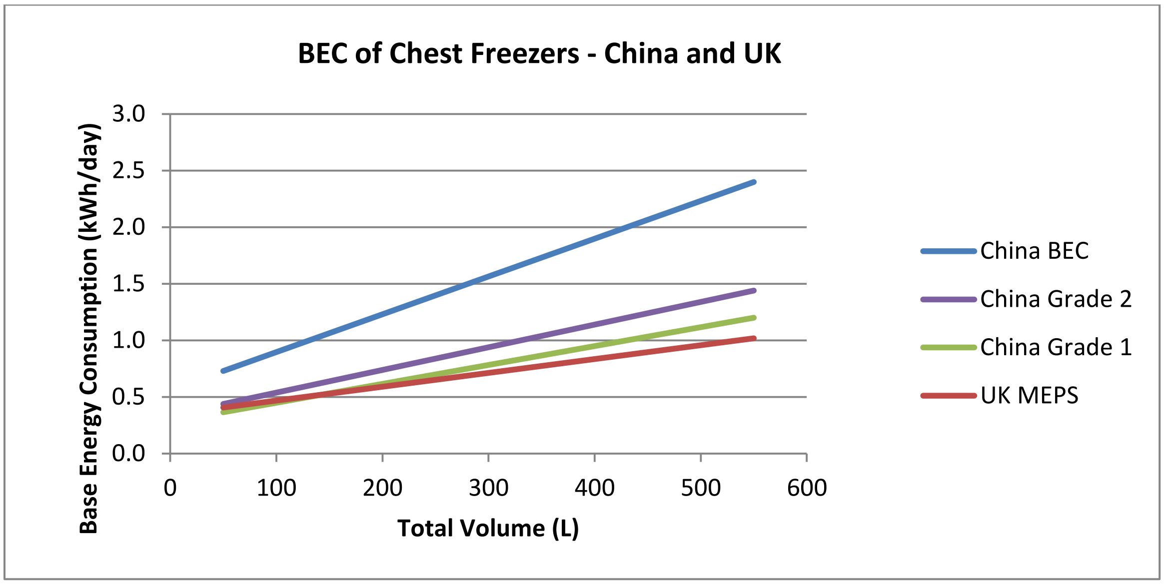
The relevant volume adjustment factor W_C (from Table 8) is 2.15. M and N for chest freezers in China are 0.567 and 205 respectively.

Substituting the appropriate values for the volume and adjustments into equation (6), we calculate the standard energy consumption:

$$E_{base} = \{0.567 \text{ x } (0 + 2.15 \text{ x } 200 \text{ x}1.0) \text{ x } 1 + 205\} \text{ x } 1 /365 = 1.23 \text{ kWh/ 24-hr}$$

The results of applying the formula to a variety of appliance volumes are presented on Figure 12, along with a comparison of the UK level.

Figure 13 Base Energy Consumption for Chest Freezers for the UK and China



3.4.3. Canada

As mentioned in Section 3.3.3, in Canada's test method for refrigerators, refrigerator-freezers and freezers there are three major factors that are different from the China and UK test methods that affect the measured 24-hr. energy consumption:

1. different ambient temperature
2. different use factors
3. different controlled temperature settings in compartments

The adjustments needed in order to be able to compare the regulated levels on a common base, were made to the base energy consumption calculation as follows:

First, because of higher ambient temperature: apply an "ambient" factor of 1.3.

Second, Canada also uses an adjustment factor K= 0.7 for chest freezers to adjust for usage.

Third, since the freezer temperature during the test in Canada is higher than that used in the UK and China (-15°C vs. -18°C in the UK and China) an adjustment needs to be made to the annual energy consumption.

Finally, the adjustment factor used for the adjusted volume calculations of freezers in Canada is different than the UK's because of the higher ambient and lower fresh food compartment temperature (1.73 in Canada vs. 2.15 in the UK). Since we are comparing the BAE_C of freezers in Canada against the BAE_C in the UK while compensating for the lower ambient, the adjustment for volume in Canada is changed to be the same as for the UK and China, i.e., 2.15

To summarize:

When comparing the Canadian test method for measuring the annual or daily energy consumption of chest freezers with those in the UK (which are the same as in China), the following adjustments need to be made to the Base Energy Consumption calculation due to the test conditions in Canada:

1. Increased consumption by 1.3 because of a higher ambient temperature
2. Lower "usage factor" for chest freezers of 0.7
3. Decreased consumption by 1/1.07 because of the 3 C degree higher freezer temperature during the test than in the UK
4. A volume adjustment factor of 2.15 (instead of 1.73), same as in the UK.

The formula for maximum allowable AEC in Canada for chest freezers is normally:

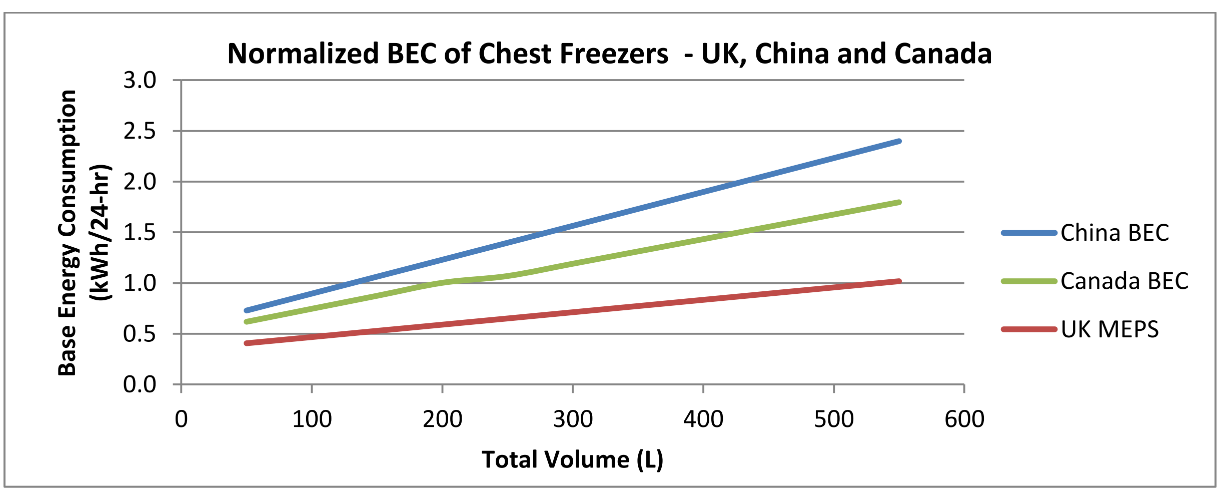
AEC = 0.35 AV + 143.7 for V > 210L

In order to normalize the comparison of appliance performance, we apply the inverse of the adjustments (1 to 4) to the Base Energy Consumption of a 400 L chest freezer as follows:

AEC ={ 0.35(400 x 2.15) + 143.7 }x 1.07/(1.3 x 0.7) = 522.9 kWh/year or 1.43 kWh/24-hr

The results of applying the formula to a variety of appliance volumes are presented on Figure 13 in the form of Base Energy Consumption (BEC) vs. Total Appliance Volume (not total adjusted volume) all economies are normalized to UK conditions.

Figure 14 Normalized Base Energy Consumption for Chest Freezers for the UK, China and Canada (UK conditions)

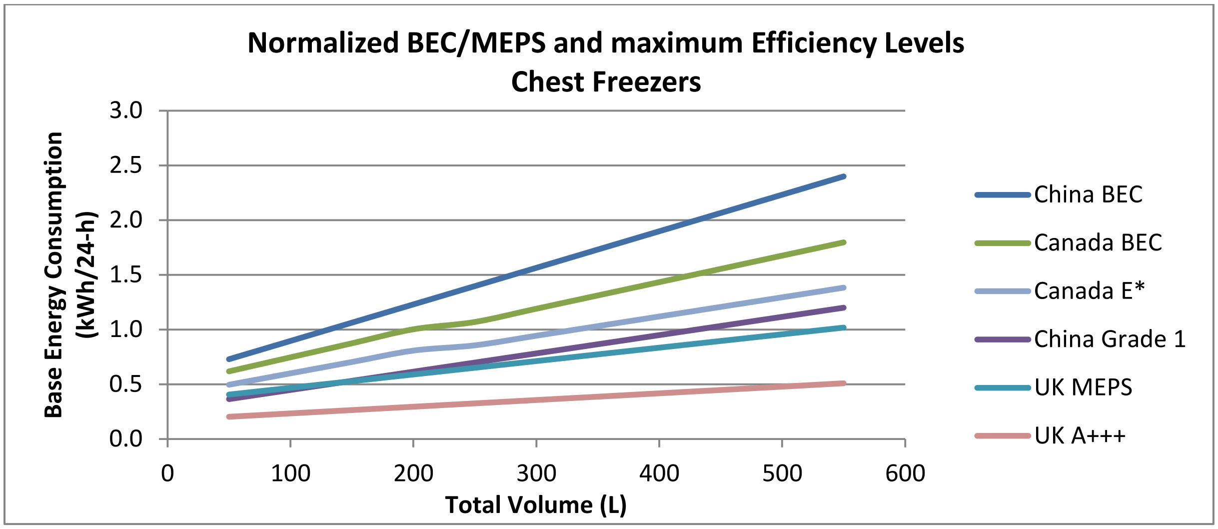


Note that the jog in the Canadian BEC level is caused by a less restrictive requirement for compact chest freezers:

AEC= 0.37 AV + 152 for compact freezers (below 219L)

On Figure 14 the China Grade Level 1, the UK Level A^{+++} and the ENERGY STAR level for Canada, normalized to the UK conditions were added to the Base Energy Consumption Levels for the UK, China and Canada.

Figure 15 Normalized Base Energy Consumption and Highest level for Chest Freezers for the UK, China and Canada (UK conditions)



As stated earlier, the BEC levels for China and Canada are representative of the MEPS for each country. For the UK, the MEPS are represented by 44% of the BEC (starting in 2012, to be reduced to 42% in 2014. In practice, Chinese and Canadian product consumption levels are lower than the BEC. In China, the highest grade (Level 1) must be below 50% of the BEC. In Canada, high efficiency models are rated about 15 -20% below the BEC level depending on appliance types. In the UK, the highest efficiency units rated A+++ must be below 22% of the BEC. Thus the UK has the most stringent requirement for A+++ rated chest freezers, followed by China Grade 1 level and finally by the ENERGY STAR level for Canada and the US. Regarding MEPS levels for chest freezers, the UK has the most stringent MEPS, followed by Canada with less stringent levels, and by China with the least stringent levels.

3.4.4. Summary Observations on Freezer MEPS levels and highest performance class levels in the three Economies

In order to compare the current regulated levels of chest freezers across the three economies, three sizes of freezers were selected: small, medium and large volume, and the normalized BEC and highest grade level energy consumption for each appliance were calculated, assuming volumes of 150 L, 350L and 550 L. For each of these, the BEC, the normalized MEPS and the estimated normalized consumption of the highest grade level were calculated. The results are presented on Table 21.

Table 21 Comparison across economies of normalized maximum daily consumption levels for BEC, MEPS and highest grade level for various freezer volumes

Economy	BEC			MEPS			Highest Grade		
	150 L	350L	550L	150 L	350L	550L	150 L	350L	550L
Canada	0.87	1.31	1.80	0.87	1.31	1.80	0.70	1.03	1.38
China	1.06	1.73	2.40	1.06	1.73	2.40	0.53	0.87	1.20
UK	1.20	1.76	2.31	0.53	0.77	1.02	0.26	0.39	0.51

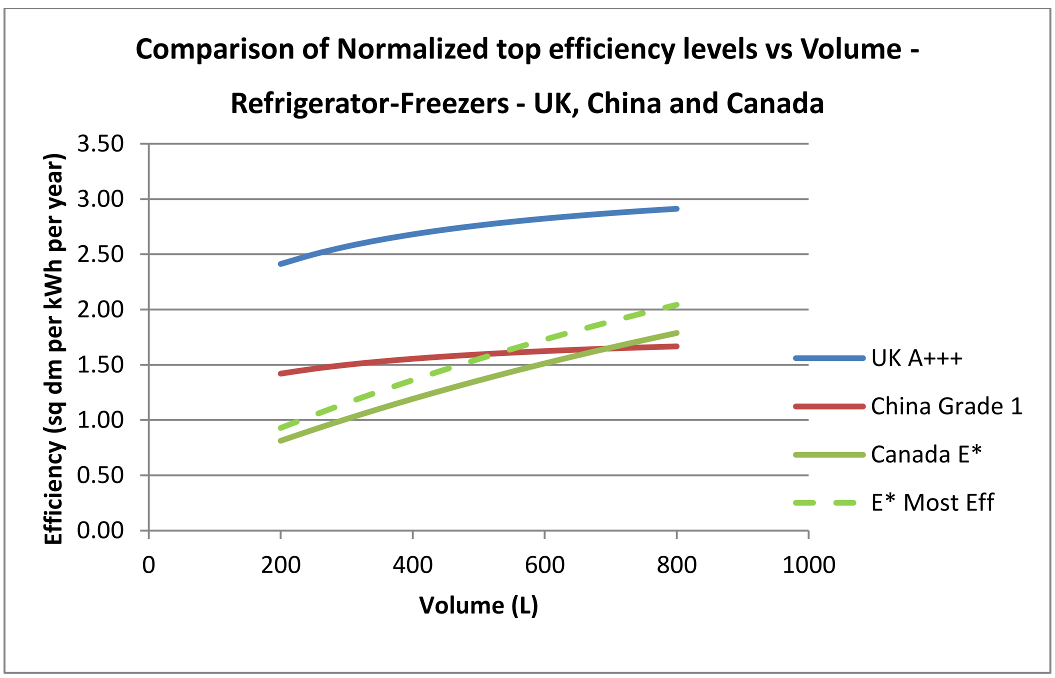
The UK's MEPS levels are currently more stringent than Canada's levels, while Canada's levels are more stringent than China's for all chest freezer sizes, especially at higher volumes. The UK's requirements for the highest grade freezers are considerably more stringent than China's levels and much more stringent than Canada's.

An important observation is that the required base energy consumption levels are dependent on appliance volume (or adjusted volume). How do we know that the product efficiency levels that correspond to these regulated levels are not biased by the volume of the appliance? The answer is that we do not currently have a way of determining any bias using the existing metrics. A novel method of defining and evaluating the *efficiency* of refrigerated appliances is described in Annex 2. The method, which is totally independent of appliance volume, was used to calculate the implied efficiency levels corresponding to the Normalized Base Energy Consumption and to the various Grade Levels across economies. The new efficiency metric was designed to provide a measure of efficiency that is expected to be independent of unit volume; the novel method is defined in detail in Annex 2, while the answer to the question of built-in bias in the highest grade levels set by regulations in the three economies is addressed in the following section.

4. Proposed new definition of "Efficiency"

From Tables 21 and 22, it can be seen that the MEPS and the Grade Levels defined by the three economies do not appear to follow any particular pattern as volume of the appliance changes. In order to understand the resulting effectiveness of doing the cooling job implied by the legislated levels, an attempt was made to define the "Efficiency" of a refrigerating device. The new concept is presented in Annex 2. The new definition of efficiency is in terms of adjusted interior surface area (in dm^2) divided by the amount of energy consumed by the appliance per year. The efficiency thus defined can be used not only to measure the efficiency of any refrigerated appliance, but also to determine the efficiency level implied by the regulated levels in each economy. One way of visualizing this new metric, is to picture the amount of surface area that could be cooled for an entire year by 1 kWh of electrical energy. If we use 1 dm^2 as the unit of area, then a cube with 1 dm sides would sustain a volume of 1 litre, and the surface area would be 6 dm^2. As an example, the implied efficiencies of the highest grade refrigerator-freezers on Table 19 were calculated and are presented on Figure 15 and summarized on Table 22. The units assumed in the tables are dm^2 per kWh/year.

Figure 16 (from Annex 2) Normalized Efficiencies of small volume and large volume Refrigerator-Freezers at the highest performance level for the UK, China and Canada



As in the case of Figure 10, the "ENERGY STAR Most Efficient" classification was also included in Figure 15 to give an indication of the improvement in efficiency resulting from a product meeting this new, more stringent requirement (12.5% improvement in efficiency)

Table 22 Comparison of Efficiencies of the highest grade level Refrigerator-Freezers according to unit volumes for various appliance volumes

Economy	Highest Grade Normalized 24-hr. energy consumption (kWh/24-hr)			Efficiency of corresponding product dm^2/ kWh/year		
	200L	**500 L**	**800 L**	**200L**	**500 L**	**800 L**
UK	0.33	0.54	0.75	2.41	2.76	2.91
China	0.50	0.81	1.11	1.42	1.59	1.67
Canada	0.97	1.11	1.24	0.81	1.36	1.79

Using the new "efficiency" metric on the top grade levels, one can notice a considerable variation in implied efficiency levels with unit volume, as well as significant variations in efficiency levels across economies for the corresponding products and volumes.

It is interesting to note that the efficiency of the Canadian refrigerator-freezers more than doubles as the volume is increased. In China, the efficiency increases only by 18% over the same volume range. In the UK, the efficiency increases by 21 %. This finding indicates that in Canada, large refrigerator-freezers are required to be much more efficient than smaller ones.

In a similar manner, the implied efficiencies of the highest grade freezers on Table 21, were calculated and are presented on Figure 16 and Table 23.

Figure 17 (from Annex 2) Comparison of Normalized top efficiency levels vs. Volume - UK, China and Canada

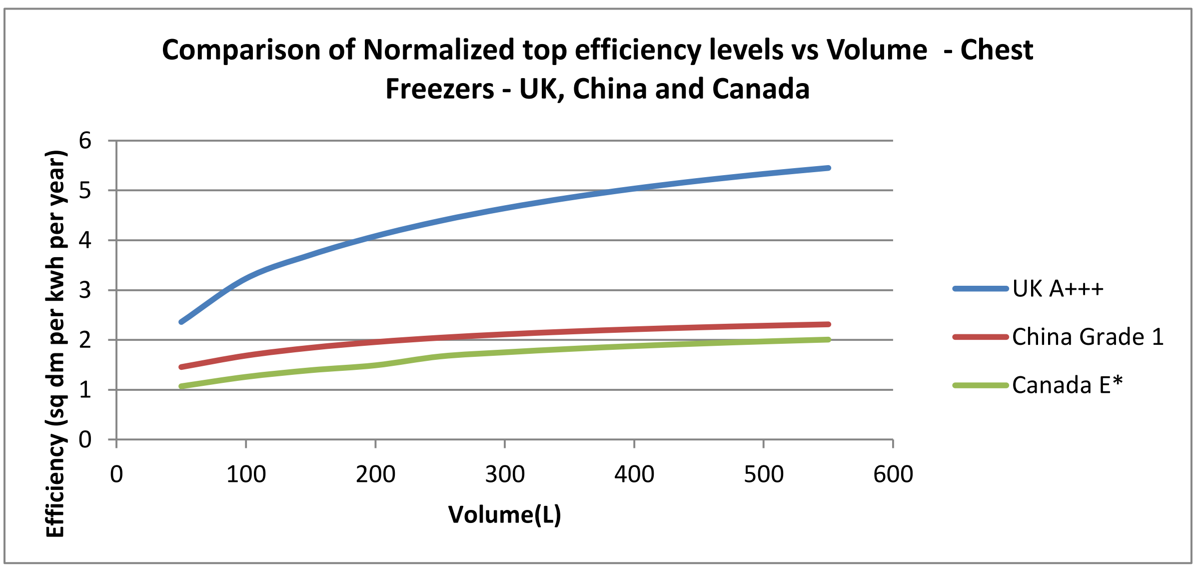


Table 23 Comparison of Efficiencies of the highest grade level Freezers according to unit volumes for various appliance volumes

Economy	Highest Grade Normalized 24-hr. energy consumption (kWh/24-hr)			Efficiency of corresponding product dm^2/ kWh/year		
	150 L	**350L**	**550L**	**150 L**	**350L**	**550L**
UK	0.29	0.43	0.57	3.71	4.85	5.45
China	0.53	0.87	1.20	1.84	2.17	2.31
Canada	0.70	1.03	1.38	1.39	1.82	2.01

We note that the efficiency level implied by the UK A+++ grade of freezer is more than twice as high as the China Grade 1 for the largest volume chest freezers. The implied efficiency in both economies appears to increase as the volume of the unit increases from 150 L to 550 L: the values for China, UK and Canada increase by 26%, 47% and 45% respectively. China's increase in efficiency with volume is not as steep as the other economies. One can conclude that the current regulated levels result in considerable amount of variation in implied required efficiency levels across economies and also across various volumes of each type of appliance.

It should be noted that the newly defined efficiency figures for refrigerator-freezers and freezers are directly comparable. One can therefore compare, for example, the ENERGY STAR levels set for refrigerator-freezers of 600 L total volume (1.5 sq dm / kWh/year) against the ENERGY STAR level for chest freezers of 600 L volume (2.0 sq dm / kWh/year) to determine the difference in efficiencies (0.5 sq dm / kWh/year)

More details of the method used are presented in Annex 2. Although internal surface area is not normally required by any refrigeration equipment standard, it is possible to estimate the internal surface area of a refrigerated appliance if the external dimensions or footprint and individual compartment volumes and door configuration are given. Please see Annex 4 for details of this calculation.

5. Testing and Verification

The similarities of test methods called up in both the UK and in China refrigerator and freezer tests provide an excellent opportunity to check the actual difference in test results between China's Standard GB/T 8059.2-1995 (Refrigerator-Freezers) and GB/T 8059.3 – 1995 (Freezers) test methods and the UK's application of Standard EN ISO 15502:2005. The test results, combined with the current methods of calculating the base daily energy consumption, can be used to not only check the precision of the test results on specific appliance models, but also undertake the verification of the claims on the product specification sheets at the same time. A round-robin test is suggested in Annex 3 to determine if there are any unforeseen inconsistencies of testing and evaluating the 24-hour energy consumption of refrigerator-freezers and freezers using the Chinese standards. The appliances could be sent to an accredited facility to repeat the tests using the ISO test standard, and finally, compare the results. This process is expected to assist in the harmonization of standards across economies and to address any unidentified issues. Please refer to Annex 3 for a recommended plan.

Conclusions

The Chinese standards currently being applied for measuring the 24-hour energy consumption of refrigerators, refrigerator-freezers and freezers use very closely equivalent test conditions, ambient and compartment temperatures as called for in the UK test standard. Standard or Base Energy Consumption values, however, are quite different between the Chinese and UK economies, and the efficiency classes for labeling purposes use different levels in each economy. Round-robin tests of refrigerators, refrigerator-freezers and freezers tested to China and to UK standards are expected to be comparable because of the nearly identical requirements and test conditions. However, the comparison to the North American test method is complicated by a number of factors that may not be readily adjustable including different ambient temperature, compartment loading, controlled temperature and treatment of energy consumed during defrost.

The Canadian refrigerating appliances are similar to US appliances, are tested the same way and their performance levels are harmonized, even though the labeling in each country is different. The test conditions called for by the Canadian standard are quite different from the conditions called up by the Chinese standards, making it necessary to adjust the measured 24-hour energy consumption by compensating for the differences in test conditions and usage factor.

The exploration of the differences in the way that product performance is evaluated and compared across economies revealed a number of factors that, if addressed in the future, could greatly simplify the comparison of performance across economies. The main observations were:

1. Using the exact same test method and the same ambient and operating temperatures simplifies comparison of performance. This could be achieved through the adoption of an international standard accepted by many countries.

2. Classifying products with similar features together (and possibly having more categories) allows more flexibility for the Regulator to set maximum consumption levels, compared to having few classifications and using unique adjustments for particular features (such as through the door ice-service, different temperature classes, large or small volume units, freezer configuration, built-in, etc).

3. In cases where adjustment factors must be used, making the adjustment on the whole equation of the standard energy consumption, rather than on the adjusted volume portion, has the benefit of avoiding a further volume bias that would otherwise result.

4. The measurement of energy consumed as a result of using anti-condensation heaters should be included so as to encourage the industry to find alternatives or more efficient ways of reducing this important component of energy use.

5. The application of a new definition of efficiency has the potential to assist China in assessing the likely impact of new grade levels on the efficiency of the products according to volume.

The calculation of base energy consumption varies across economies, likely reflecting the local economic conditions, level of service required, cost of electricity, local product costs, payback period for the more efficient models as perceived by the consumers and other factors.

For both refrigerator-freezers and chest freezers, comparing the daily energy consumption requirement for the highest grade levels, the UK (A+++) is the most stringent, followed by China (Grade 1), and lastly by Canada's "high energy efficiency" level (ENERGY STAR).

The proposed new definition of "Efficiency" provides a new perspective on performance levels of refrigerated appliances and may be useful to avoid setting performance or grading levels with a volume-based bias that can encourage the development of larger rather than more efficient appliances.

The new definition of efficiency also opens the door to the possibility of setting efficiency levels that are independent of the technology used, replacing the need for sub-classification of appliances into classes (refrigerators, freezers, refrigerator-freezers, etc) and for various configurations (side-by side, top freezer, bottom freezer, with ice maker, etc).

Although a round-robin test between China and Canada would not really help in the development of a precise set of correlation factors, it could provide a way of comparing the test results against the estimates made in Section 2.1 of this report.

Recommendations

In light of the fact that China is in the process of updating the performance requirements for refrigerators, refrigerator-freezers and freezers, CNIS may find it useful to consider the findings in this study, which led to the following recommendations:

1. The MEPS levels for China should be made more stringent over time, making sure that the values for large volume appliances are lowered sufficiently to avoid a bias towards the use of larger appliances that would otherwise be allowed to consume more energy.

2. The slope of the line representing the implied new efficiency metric of the BEC, MEPS and Grade levels, in a and unbiased manner, determines the relative "efficiency" of small vs. large appliances. The difference in slope of the highest grade appliances between Canada and in China suggests that the China levels are less stringent for the large volume units than the smaller volume units.

3. The adoption of suitable international standards is recommended in order to avoid re-testing products for export markets and also to facilitate the comparison of performance across economies.

4. China should consider adopting higher grade levels that closely match the UK's A+++ level for both refrigerator-freezers and chest freezers.

5. A classification of refrigerator-freezers type by configuration (top- side- or bottom freezer) helps to distinguish the existing differences in efficiency levels among the various configurations.

6. Ice-making and through the door ice service contribute to energy consumption and are worth considering as additional basis for classification.

7. Tropical climate appliances, if fairly common for use in China, could also be a separate set of classifications. Otherwise, just rating a product as being T class can provide a loophole for less efficient models.

The above recommendations could result in the elimination of three adjustment factors. China currently has seven product types, the UK 10 types, and Canada 22 types. In general, when more appliance types are defined, then fewer adjustment factors need to be developed and applied for calculating the base performance and tier level. When built-in models become more popular in China, a new built-in category could be considered.

8. It is recommended that if an adjustment factor is needed, that it be formulated to apply to the entire linear equation rather than to the calculation of adjusted volume to avoid a further volume bias.

9. Including the use of anti-condensation heaters during testing in the measurement of performance would not only provide a more realistic measurement, but also motivate consideration of design changes to employ more efficient or effective means to control surface condensation.

10. It is recommended that the proposed new *Efficiency* measurement be considered as a means to check the dependence of the new MEPS and Grade levels on volume to ensure that no undesirable bias favoring larger volumes is built into the levels being set.

References

/1/ Freezer and Freezer Energy Consumption", ASHRAE Transactions, Vol. 83, No. 1, 1977

/2/ GB 12021.2-2008 Minimum Allowable Values of Energy Efficiency and Energy Efficiency Grades for Household Refrigerators (Summary). (2008). *China Energy Efficiency Standards*

/3/ Commission Delegated Regulation (EU) No 1060/2010 of 28 September 2010, *Official Journal of the European Union*

/4/ CSA Standard C300 – 08 Energy performance and capacity of household refrigerators, refrigerator-freezers, freezers, and wine chillers.

/5/ S.Stricker, Analysis of Refrigerated Appliance Data – China. CLASP internal Report, Feb. 15, 2013

Annex 1. Comparison of Standards

This section presents a detailed comparison of test conditions and requirements for the individual test methods used in each economy for refrigerators, refrigerator-freezers and freezers. The final page contains the notes associated with the specific entries.

Country, Products covered , standard	Equivalent to:	Scope	Suitable for China's Type#	AMBIENT Class SN,N,ST	AMBIENT Class T	Humidity in % or Dew Point (°C)
China Refrigerator freezers not frost-free GB/T8059.2 1955	ISO 8187 1991	not forced air, single and multiple cabinet temp control	China Type 4 refrigerator-freezers (European "Type 1": 1 temp control. "Type 2": 2 temp controls)	25 ± 0.5K	32 ± 0.5K	45-75%
China Chest freezers GB/T 8059.3-1996	ISO 5155 1996	Freezers not forced air cooling	China Type 7: chest freezers	25 ± 0.5K	32 ± 0.5K	45-75%
China Frost-free Refrigerator-freezers and Upright Freezers GB/T 8059.4-1993	ISO 8561	Refrigerator-freezers forced air cooling	China Type 5: Frost-free refrigerator-freezers and China Type 7: upright freezers	25 ± 0.5K	32 ± 0.5K	45-75%
United Kingdom Frozen food cabinets and Freezers EN ISO 15502:2005	EN ISO 15502:2005	(Refrigerators incorporating freezers use ISO 8561)††††	China Type 6 Frozen food holding cabinets and chest freezers	25 ± 0.5K	32 ± 0.5K	< 75% For condensation tests, dew points: +19C ± 0.5 K for class SN and N appliances; + 27 C ± 0.5 K for class ST and T appliances.
Canada Refrigerators, Refr-freezers, Freezers C300 - 08	C300 - 08	Ref-freezer, freezers and wine chillers (22 different types are covered)	All China Types	(No check on class) 32.2 ± 0.6°C	32.2 ± 0.6°C	For long time automatic defrost, with door openings: 26.6 ± 1.1 °C DB and 19.4 ± 0.6 °C WB

				Test Conditions for Refr. & Refr-Freezers					**Freezers**
			Fresh food	**1-star freezer**	**2-star freezer**	**3-star freezer**	**cellar**		**Internal temp**
Country, Products covered , standard	**Anti-cond. heater during Test**	**Defrost cycle included**	**All-Refrigerator**					**Notes on Test method *** of Refrigerator-freezers**	**All- Freezer**
China Refrigerator freezers not frost-free GB/T8059.2 1955	off (unless moisture appears during condensation test)	not addressed	5 C	N/A	-12 C	-18 (warmest M package temperature)	T= 12C	Interpolate between 2 or more runs to match FF and F temps	N/A
China Chest freezers GB/T 8059.3-1996	off (unless moisture appears during condensation test)	not addressed	N/A	N/A	N/A	=<-18°C	N/A	Interpolate between 2 runs to match required temp.	-18C
China Frost-free Refr-freezers and Upright Freezers GB/T 8059.4-1993	off (unless moisture appears during condensation test)	not addressed	≤ + 5C	N/A	≤ - 12C	≤ - 18C	N/A	Interpolate between 2 runs to match FF and F temps	-18C
UK Frozen food cabinets and Freezers EN ISO 15502:2005	off (unless moisture appears during condensation test)	not addressed	N/A	N/A	≤ - 12C	≤ - 18C	N/A	Interpolate between 2 runs to match required temp.	-18C
Canada Refrigerators, Refr-freezers, Freezers C300 - 08	both on and off, results are averaged.	6 types are covered	3.3 °C	N/A	–9.4 °C	–15.0 °C	N/A	Interpolate between 2 runs to match FF and F temps*****	-17.8C

	kWh / day Calculation	Daily energy to be within 15% of claim						
Country, Products covered , standard	Clause #	(test 3 more if not)	How is Defrost energy measured?	Fresh food compartment Loading	Freezer loading for 24 hr consumption test	Door openings	Freezing Capacity "Light load" test	Ice making test
China Refrigerator freezers not frost-free GB/T8059.2 1955	15, 15.2.2.2	Within 15% of claim	Include integral # of defrost cycles		Filled to capacity	none		Comparable
China Chest freezers GB/T 8059.3-1996	15	Within 15% of claim	N/A		For V<50 as many as possible For 50<V≤ 100 : 40 kg/100 L For V>100 : 25 kg/100 L *	none		
China Frost-free Refrigerator-freezers and Upright Freezers GB/T 8059.4-1993	15.3	Within 15% of claim		3 packages in FF section and and 3 in cellar	For V<50 as many as possible For 50<V≤ 100 : 40 kg/100 L For V>100 : 25 kg/100 L *	none	yes	yes**
United Kingdom Frozen food cabinets and Freezers EN ISO 15502:2005	15.3	Within 15% of claim			as many packages as can be fitted in	none	yes	yes**
Canada Refrigerators, Refr-freezers, Freezers C300 - 08	Clause 6 for refr-freezers, freezers and wine chillers	Use one-sided confidence limit equation†††			May use weighted thermocouples or 75% of max capacity load	No, but there is an optional test for variable defrost control	Only reported for freezers (upright and chest)	none

	Adjustments				Adj Factor	Adj Factor	Adj Factor	Adj Factor	
Country, Products covered , standard	**Usage factors**	**How temp is measured**	**Precision Delta T**	**EE Regulation**	**Refr-freezer**	**Freezer**	**Auto def**	**Refr or wine cooler**	**MEPS**
China Refrigerator freezers not frost-free GB/T8059.2 1955	None	25 g brass or M package	Temp ±0.3K	GB12021.2-2008	None given	None given	None given		none
China Chest freezers GB/T 8059.3-1996	None	25 g brass or M package	Temp ±0.3K	GB12021.2-2008	None given	None given	None given		none
China Frost-free Refrigerator-freezers and Upright Freezers GB/T 8059.4-1993	None	25 g brass or M package	Temp ±0.3K	GB12021.2-2008	None given	None given	None given		none
United Kingdom Frozen food cabinets and Freezers EN ISO 15502:2005	None	25 g brass or M package	Temp ±0.3K		None given	None given	None given		None
Canada Refrigerators, Refr-freezers, Freezers C300 - 08	K† = 0.7 chest freez ; K= 0.85 Upright freez K= 1 Refrig-freez F††= 0.2 for exclusion of defrost cycle	25 g brass mass or in M packages	± 0.5 °C resolution of digital eqpt to be 0.1 °C	Canada: Energy Efficiency Act and latest Regulation	1.63	1.73	N/A	1	Table 1 contains MEPS and High Efficiency limits

Notes

*	For V < 50 L, as many packages as possible, consistent with the storage plan but leaving space to accommodate the light load
**	For the ice making test, ambients are: +32 for class SN and N appliances; +38 for class ST ; + 43 for class T
***	The first four standards do not deal with the issue of defrost cycles during the measurement of energy consumption, nor how to deal with the various types of defrost initiation processes.
****	use weighted thermocouples
*****	Repeat with anti-sweat heaters on and off. Consumption will be the average of both sets of tests.
†	k = correction factor to adjust for average usage, dimensionless
††	F = ratio of per-day energy consumption in excess of the least energy and the maximum differences in per-day energy cons.
†††	Sampling size explained in Appendix B (informative)
††††	"one-", "two-" and “three-Star” compartments are covered in ISO 7371

Annex 2. Redefining the "Efficiency" of refrigerators and freezers

Efficiency of a product is normally defined in terms of:

What we want to achieve divided by what we have to pay for, expressed in appropriate units. Examples of efficiency measures are:

For lamps, lumens output per watt input;

For furnaces: rate of useful heat output divided by rate of fuel input;

For automobiles, miles driven per unit of fuel consumed;

For refrigerators, consumers want to maintain a constant temperature difference across the wall of the refrigerator cabinet of certain volume in order to keep food cold. What they pay for is the amount of energy the appliance consumes per year. The mechanisms involved in a refrigerator are the heat transfer from the room through the walls of the compartment into the compartment interior, and the removal of precisely the same amount of heat from the interior by the refrigeration system. We can therefore define efficiency of a refrigerator (operating at a fixed constant temperature-difference to the room) as the amount of surface area of the compartment walls being cooled divided by the amount of electrical energy consumed per year:

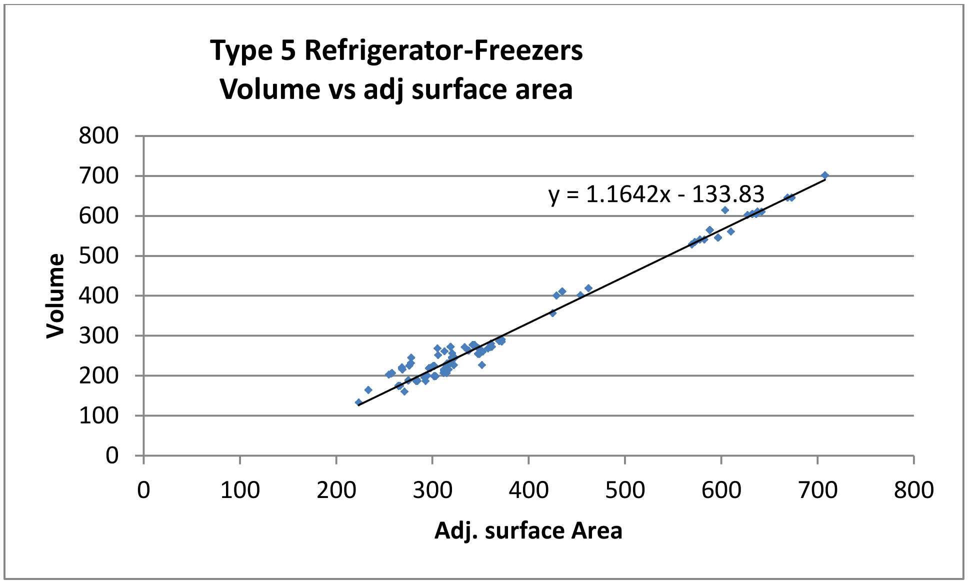
$$\text{Efficiency} = \frac{\text{amount of refrigerated compartment wall area}}{\text{(amount of energy consumed per year)}} \qquad .....(1)$$

The reason that surface area is the more appropriate variable to use (rather than compartment volume) is because there is a linear relationship between heat flow and surface area and heat flow and temperature-difference. One obstacle in using surface area for the calculation of efficiency is that appliances are normally identified and labelled according to the total storage volume and not surface area, since volume is a very important factor in the purchasing decision of the consumer. Measuring and reporting the interior surface area of each compartment should not pose any problem, should this method of calculating efficiency be adopted in the future. In the meantime, it is possible to estimate the individual compartment surface areas by using the external appliance dimensions and the individual compartment volumes. One method is described in Annex 4. The method uses the footprint of the unit and the compartment volumes to estimate the length, width and height of each compartment. The second variable is the temperature difference between the exterior and interior of individual compartments that are maintained at different temperatures; we can adjust the surface area directly in proportion to the increase in temperature difference across the wall of the compartment, using the same adjustment factors as are currently being used in the local economy's regulations, but applying the adjustments to the surface area of each compartment, not to the volume of each compartment. Therefore for refrigerators, refrigerator-freezers and freezers, the Efficiency equation becomes:

$$\text{Efficiency} = \frac{\text{Total Adjusted Wall Area (dm}^2\text{)}}{\text{(Amount of energy consumed per year (kWh/year)}} \quad .....(2)$$

The method described in Annex 4, combined with the appropriate adjustment factor, was used to estimate the total adjusted surface area of Chinese refrigerator-freezer models collected via a web search of various manufacturers' models. Next, the total volume of each individual model in the database (in L) was plotted against the calculated adjusted surface area (in sq dm) for the corresponding appliance, for all refrigerator-freezers having similar configuration (top or bottom freezer). The results are plotted on Figure 17.

Figure 18 Plot of Total unit Volume vs Total Adjusted Surface Area of Type 5 Refrigerator-Freezers



The regression line through the points is fairly linear, and the formula of the linear equation describes the relationship between appliance total volume (in L) and adjusted surface area (in squared decimeters, dm^2).

$$\text{Volume} = 1.1642 \times (\text{Adj S Area}) - 133.83 \quad .... (3)$$

$$\text{Therefore: } (\text{Total Adjusted Surface Area}) = (\text{Volume} + 133.83) / 1.1642 \quad ....(4)$$

The variations of the points away from the regression line reflects the fact that products vary slightly in proportions of width, depth and height of compartments, affecting the aspect ratio somewhat, and thus also affecting slightly the relationship between volume and surface area.

Now we can estimate the efficiency implications of the Base Energy Consumption for the corresponding product in each economy over a range of total volumes.

A2.1 Efficiency Test on Normalized Base Energy Consumption across Economies

A2.1.1 Refrigerator-Freezers

In order to compare the efficiency level implied by the base energy consumption for each type of product in each economy, the implied efficiency of a product type can be estimated at each volume as follows:

For each volume to be explored, calculate the total adjusted surface area using equation (4).

Then substitute the total adjusted surface area into equation (2) and place the corresponding normalized BEC multiplied by 365 in the denominator of the same equation to obtain the following:

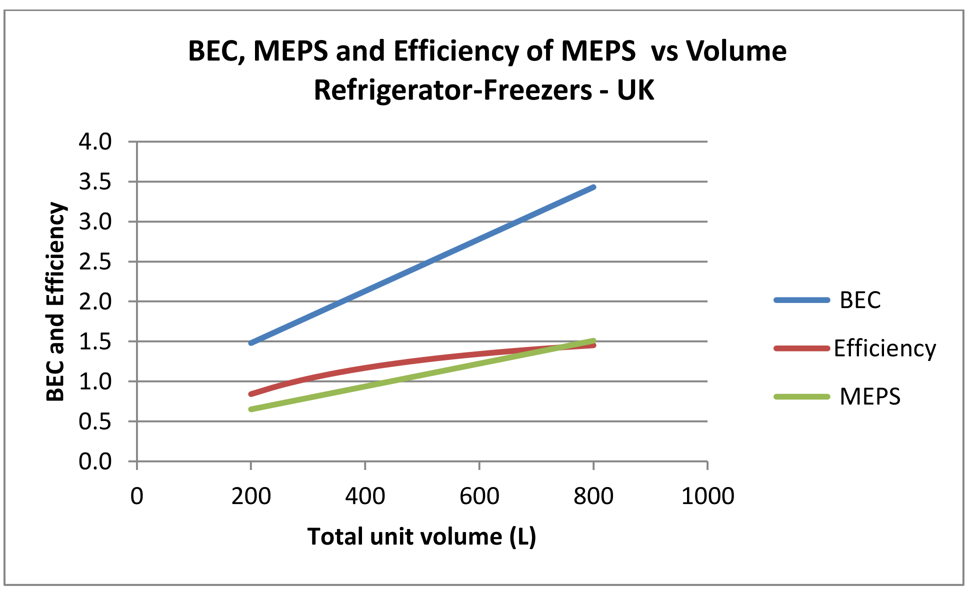
$$\text{Energy Efficiency}_{\text{at a given volume}} = \frac{\text{total adjusted surface area}_{\text{at the same volume}}}{\text{BEC}_{\text{at the same volume}} \times 365} \quad \text{.......... (5)}$$

In this manner, one can calculate the efficiency at each appliance volume. This calculation was conducted for the normalized BEC for each appliance and for each economy and the results are presented on Figures 18 to 30.

Implied Efficiency of Base Energy Consumption in each economy

The graphs display the normalized BEC for each country for the corresponding appliance in kWh/day, and the calculation of efficiency in units of (dm^2 / kWh/year). Note that for the UK, the MEPS are set at 0.44 x BEC until 2014, and that for both China and Canada, the BEC is equivalent to the MEPS.

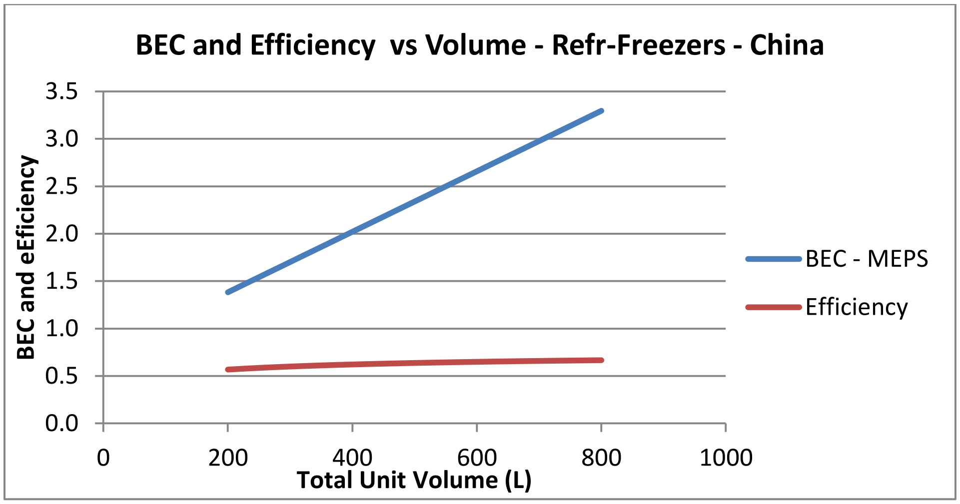
Figure 19 Normalized BEC, MEPS and Efficiency vs Unit Volume – Refrigerator-Freezers – UK



It is interesting to note that the efficiency level of units at the MEPS level (44% of the BEC) in the UK increases to double the value as the unit volume increases from 200 L to 800 L, , at an efficiency level ranging from about 0.8 to 1.5 dm^2 / kwh / year.

Next, we calculate the implied efficiency levels for the BEC in the China Regulations. See Figure 19. The BEC also represent the MEPS in China.

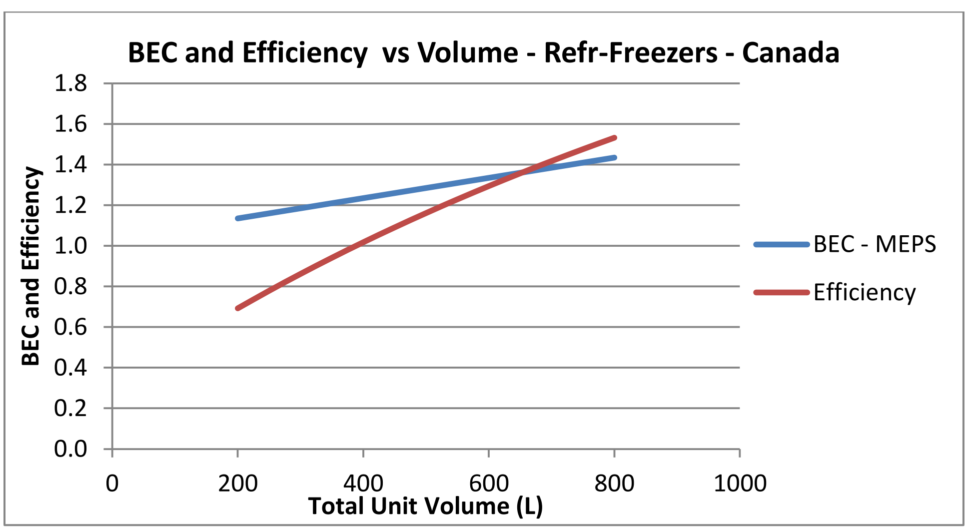
Figure 20 Normalized BEC and Efficiency vs Unit Volume – Refrigerator-Freezers – China BEC (MEPS)



In China, the BEC corresponding to the MEPS level exhibits efficiency levels that are lower than the UK levels and less dependent on unit volume, ranging between 0.6 to 0.7 dm^2 / kwh / year.

Next we calculate the implied efficiency levels for the Canadian BEC, representing the MEPS. The results are plotted on Figure 20.

Figure 21 Normalized Efficiency vs Unit Volume – Refrigerator-Freezers – Canada BEC (MEPS)

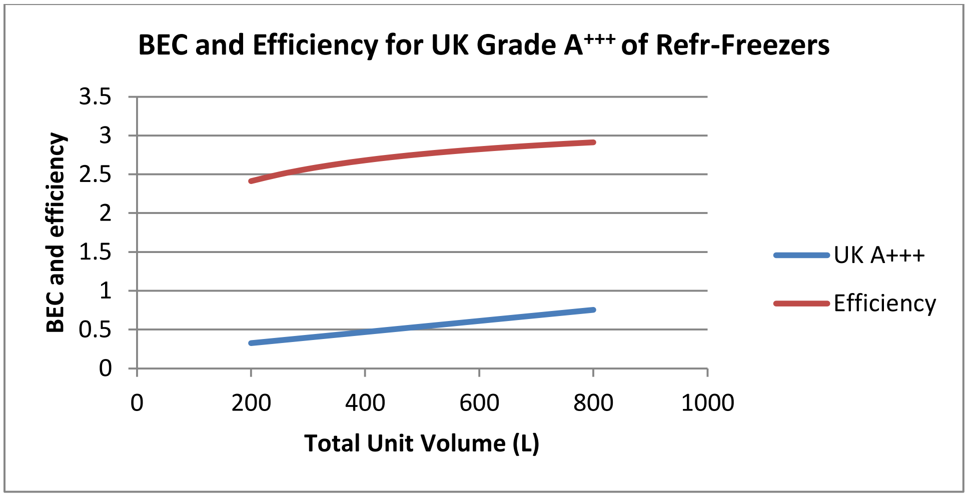


In Canada, the BEC corresponding to the MEPS level exhibits efficiency levels that are nearly the same as the UK levels, ranging between 0.7 and to 1.5 dm^2 / kwh / year.

Implied Efficiency of Highest grade level of Refrigerator Freezers in each economy

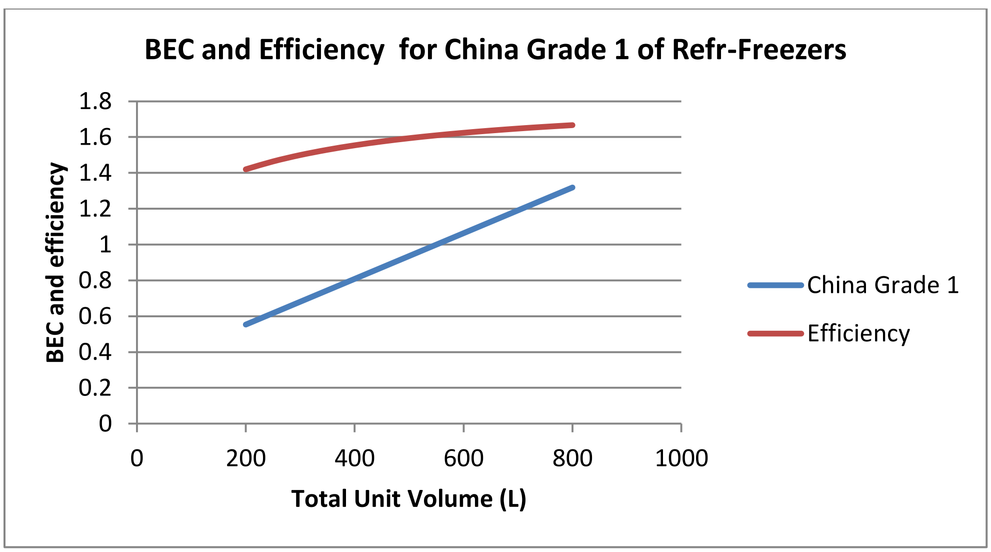
Next, let us look at the efficiency levels that correspond to the highest efficiency level in each economy, namely, level A^{+++} for the UK, Level 1 for China and High Efficiency (ENERGY STAR) for Canada (and the US). These are illustrated on Figures 21, 22 and 23.

Figure 22 Normalized Efficiency vs Unit Volume – Refrigerator-Freezers – UK Grade A^{+++}



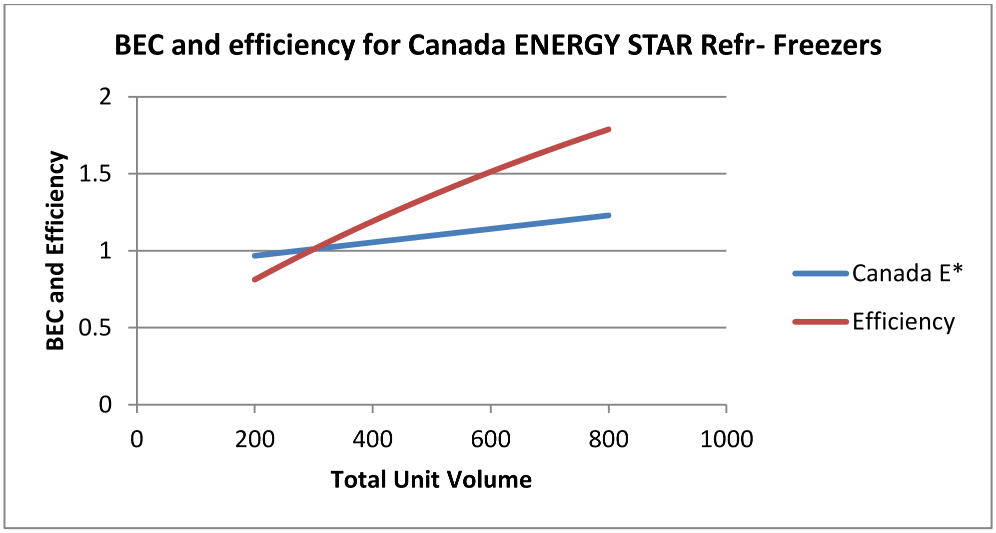
The efficiency level for units in the UK rated at the highest grade A^{+++} is significantly higher than the base level and ranges, from 2.4 to 2.9 dm^2 / kwh / year, and increases with unit volume.

Figure 23 Normalized Efficiency vs Unit Volume – Refrigerator-Freezers – China Grade 1



The efficiency level for units in China rated at the highest Grade 1, is higher than the base (MEPS) level and ranges, from 1.42 to 1.67 dm^2 / kwh / year, but considerably lower than the UK A^{+++} level and the efficiency increases with unit volume.

Figure 24 Normalized Efficiency vs Unit Volume – Refrigerator-Freezers – Canada ENERGY STAR



The efficiency level for units in Canada rated at the highest efficiency level (to meet the ENERGY STAR requirement), is higher than the base (MEPS) level and ranges from 0.97 to 1.23 dm^2 / kwh / year. The range is somewhat lower than China's Grade 1 level, but the slope of the line is tilted to make larger volume units to be more efficient.

The normalized efficiency of refrigerator-freezers that are top-rated in each economy (over the range from 200 L to 800 L volumes) were gathered together from Figures 21,22 and 23 and are presented on Figure 24 and the observations are summarized on Table 24.

Figure 25 Normalized Efficiencies of small volume and large volume Refrigerator-Freezers at the highest performance level for the UK, China and Canada

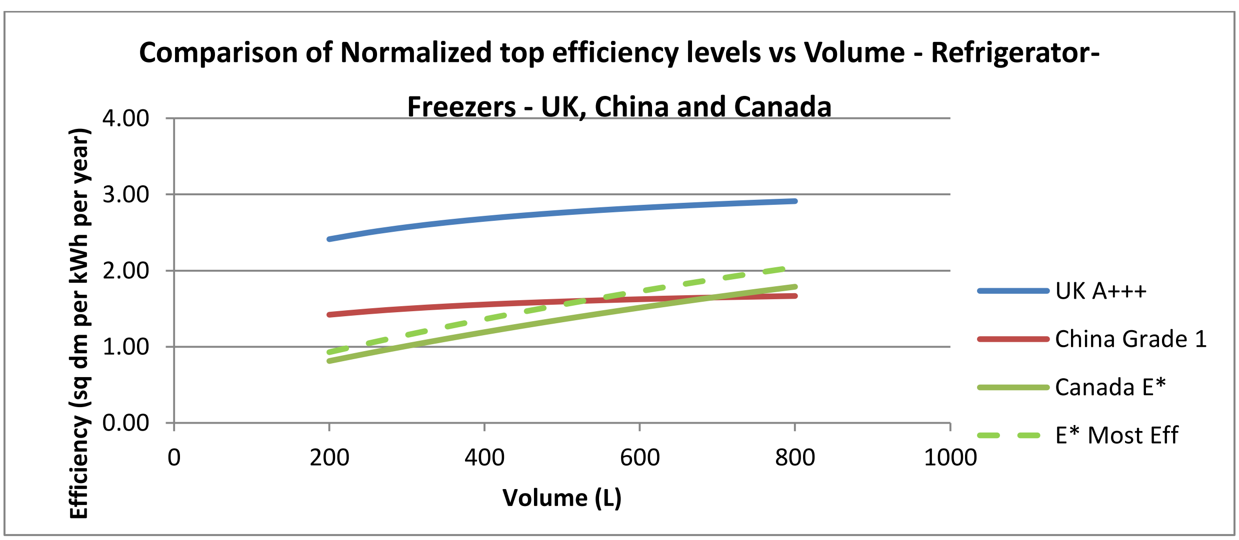


Table 24 lists the normalized efficiency levels for 200 L and 800 L refrigerator-freezers across the three economies associated with the Base Energy Consumptions and with the highest level classification of appliance performance in the corresponding economy. Note that the "ENERGY STAR Most Efficient" level (12.5% higher efficiency than ENERGY STAR level) has been plotted as a dashed line on Figure 24 to illustrate the relative improvement in efficiency that this information program represents.

Table 24 Normalized Efficiencies of small volume and large volume Refrigerator-Freezers at the Base level and at the highest performance level for the UK, China and Canada

	Appliance total volume		Ratio of efficiency levels (800L/200L)
	200 L	**800 L**	
UK Base level (MEPS)	0.84	1.45	1.73
UK Highest level A+++	2.41	2.91	1.21
China Base Level (MEPS)	0.57	0.67	1.18
China Highest level Grade 1	1.42	1.67	1.18
Canada Base level (MEPS)	0.69	1.53	2.21
Canada Highest level ENERGY STAR	0.81	1.79	2.21

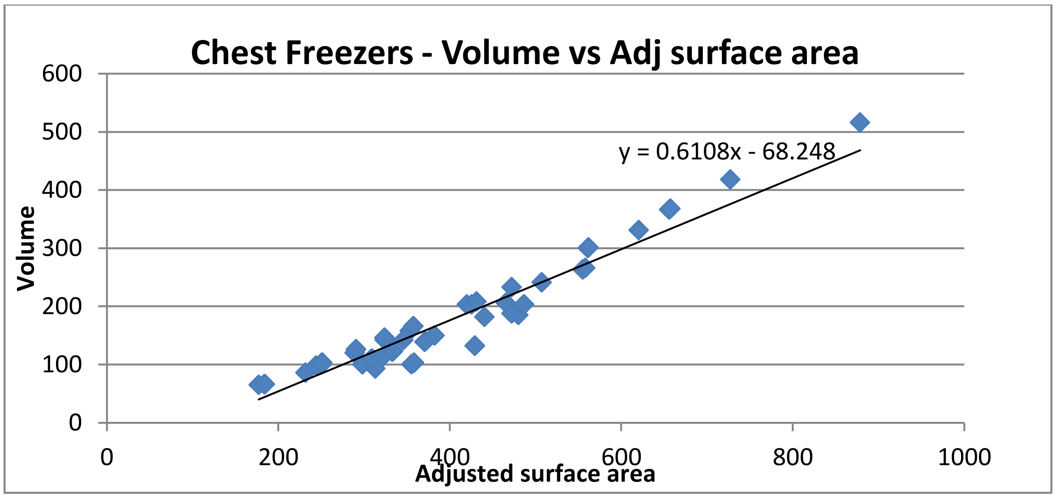
Table 24 indicates the following:

- There is a significant difference between implied efficiencies by the UK and China *MEPS* for both small and large refrigerator-freezers, with the UK efficiency levels being nearly double those of China.
- The implied efficiency of Canada's MEPS lies between China's and UK's levels.
- There are significant variations in implied efficiency between small volumes and large volumes in all countries.
- There is a big difference in efficiencies between the highest grade levels in UK and in China, with the UK efficiency levels being higher by about (2.41/1.42=) 1.7 times for both small and large volume refrigerator-freezers.
- Canada's BEC level is also the MEPS; the only other higher efficiency level that is recognized and promoted is the ENERGY STAR level.
- The ENERGY STAR implied efficiency level is lower than the China Grade 1 level for small volume refrigerator-freezers but is slightly higher for large refrigerator-freezers. The ENERGY STAR implied efficiency level is nearly the same as that of the UK's MEPS.

A2.1.2 Chest Freezers

The energy efficiency of chest freezers is calculated using the same formula (5) that was used for refrigerator-freezers, but in this case, there is no fresh food compartment, therefore the adjustment factor is applied to the freezer surface area in order to calculate the total adjusted surface area of each freezer model. Figure 25 presents the plot of freezer volume (in L) vs. adjusted surface area (in sq.dm) for freezers from the China sample of currently available products.

Figure 26 Adjusted surface area vs. Volume for random samples of Chest Freezers from the China Market



The regression line through the points is fairly linear, and the formula of the linear equation describes the relationship between appliance total volume and adjusted surface area.

Volume = 0.6108 x (Adj S Area) – 68.248 ……… (6)

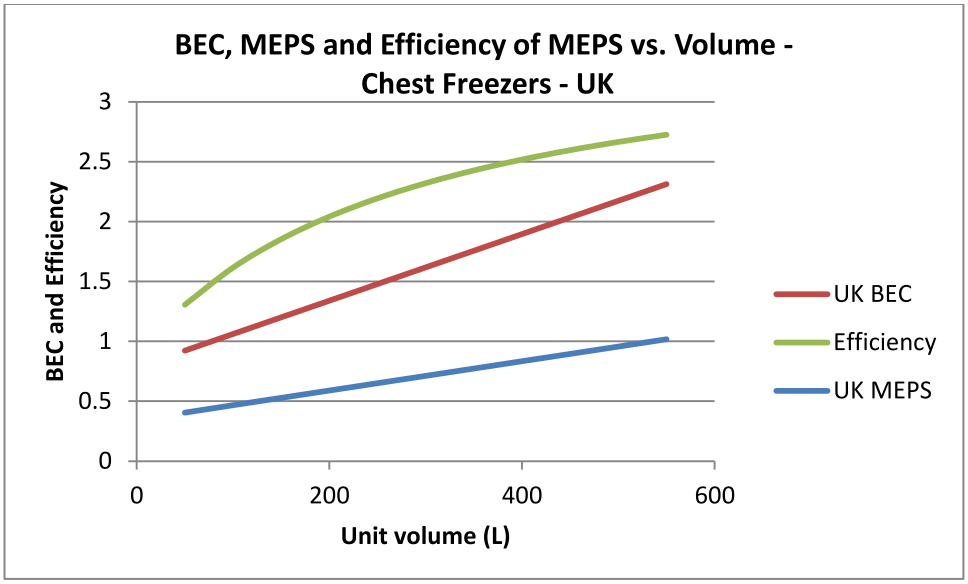
Therefore: (Total Adjusted Surface Area) = (Volume +68.248) / 0.6108 ………..(7)

The variations of the points away from the regression line reflects the fact that products vary slightly in proportions of width, depth and height of compartments, affecting the aspect ratio somewhat, and thus also affecting slightly the relationship between volume and surface area.

In a similar manner as was used in the previous section, we will estimate the implied energy efficiency (in dm^2 per kWh/year) of the normalized base energy consumption of freezers (kWh/24-hour period) over a range of volumes (in L)

We start with the estimated freezer efficiency implied by the BEC in the UK in Figure 26.

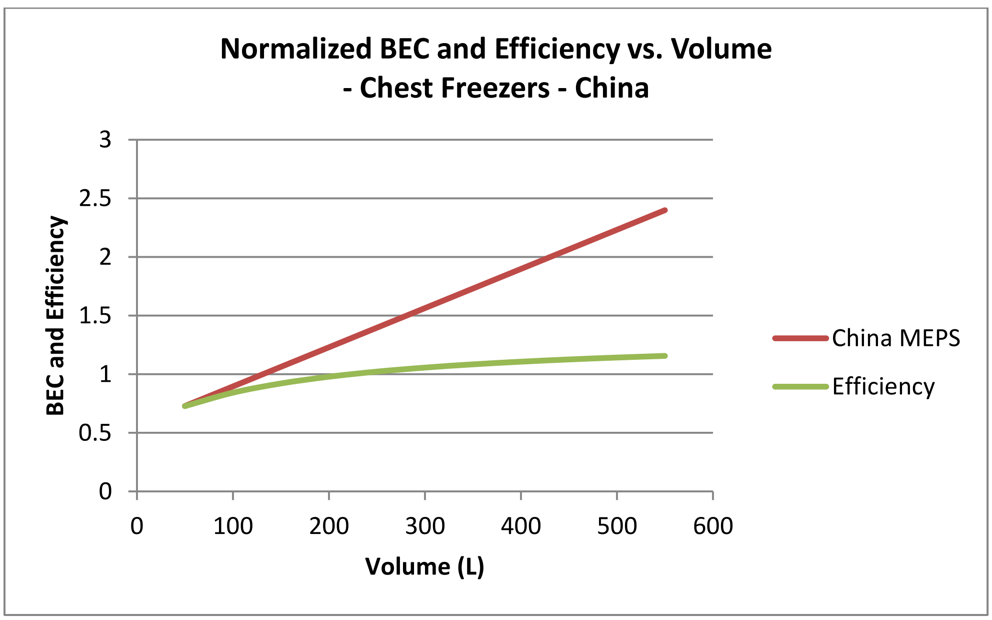
Figure 27 Normalized Efficiency vs. Unit Volume - Chest Freezer –UK BEC



It can be noticed that the implied efficiency of the MEPS increases with volume, nearly doubling as we move from 50 L to 550 L volumes.

Figure 27 presents the results for the China implied efficiency levels associated with the BEC.

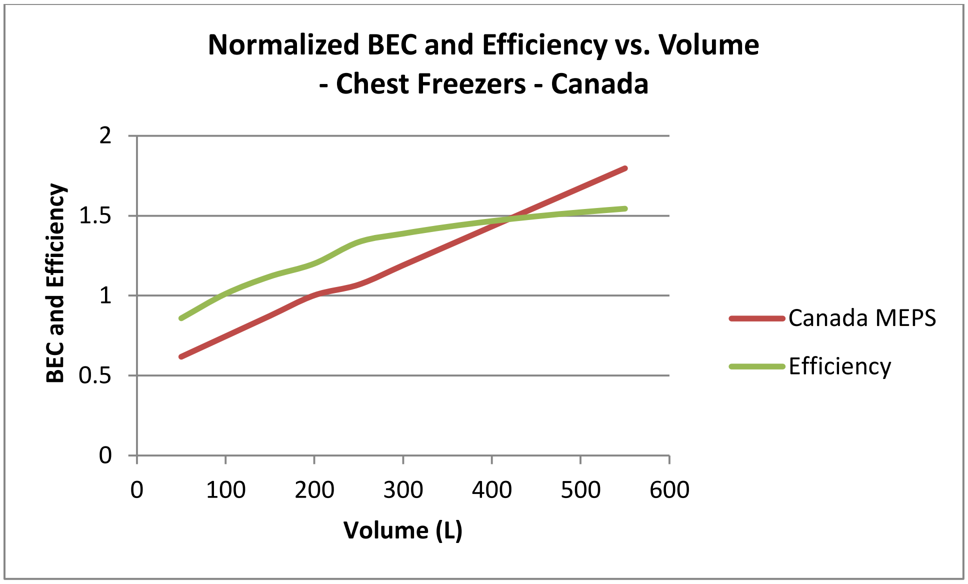
Figure 28 Normalized Efficiency vs Unit Volume - Chest Freezer –China BEC



The implied efficiency for the China BEC level is much lower than the UK, but somewhat flatter with increasing volume.

Figure 28 presents the results for the Canada implied efficiency levels associated with the BEC.

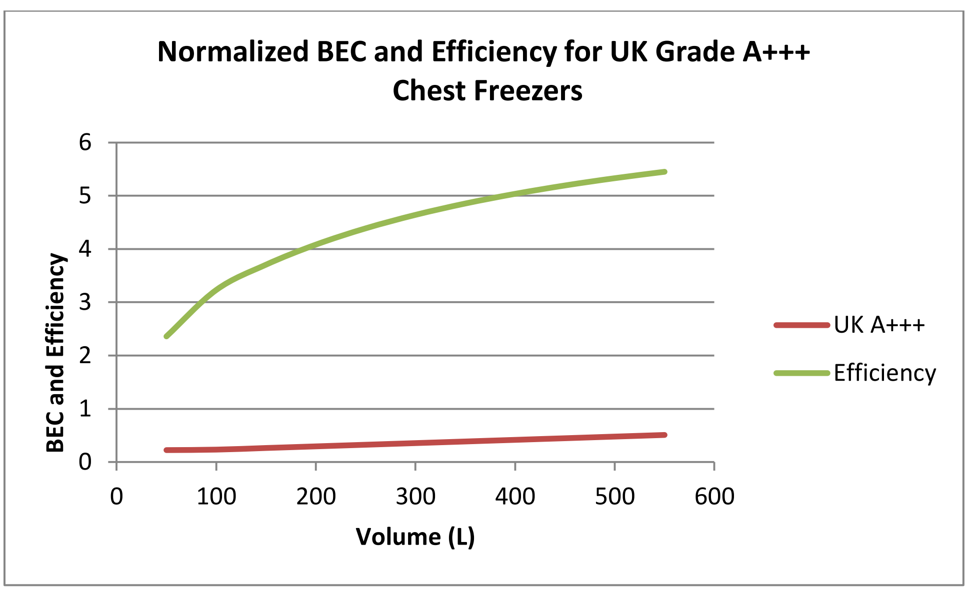
Figure 29 Normalized Efficiency vs Unit Volume - Chest Freezer –Canada BEC



The kink in each of the lines is associated with the change in BEC from compact to standard size freezers. The implied efficiency levels are lower for the smaller volumes and nearly double as we move from the smallest to the largest volumes. The implied efficiency level is somewhat higher than China's but much lower than the UK's

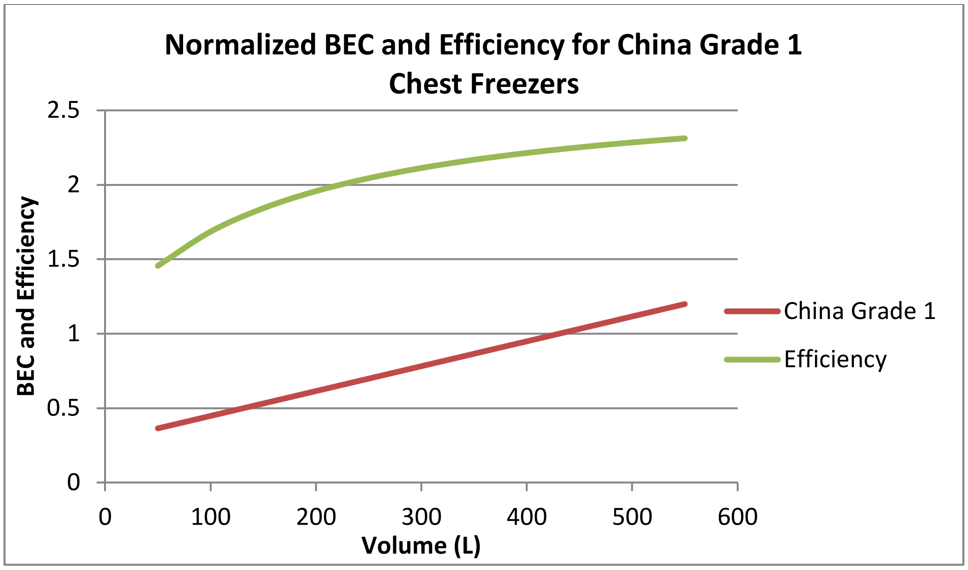
Next, we explore and compare the implied efficiency levels at the normalized maximum efficiency level in each economy. It can be noticed on Figure 29 that the efficiency level for the A+++ grade in the UK (ranging between 2.5 and 5.8) is about 5 times higher than for the base level (shown on Figure 26, ranging between 0.5 and 1), over the entire range of volumes.

Figure 30 Normalized BEC and Efficiency for UK Grade A+++ Chest Freezers



The efficiency levels corresponding to the China Grade 1 for chest freezers Level is presented next on Figure 30.

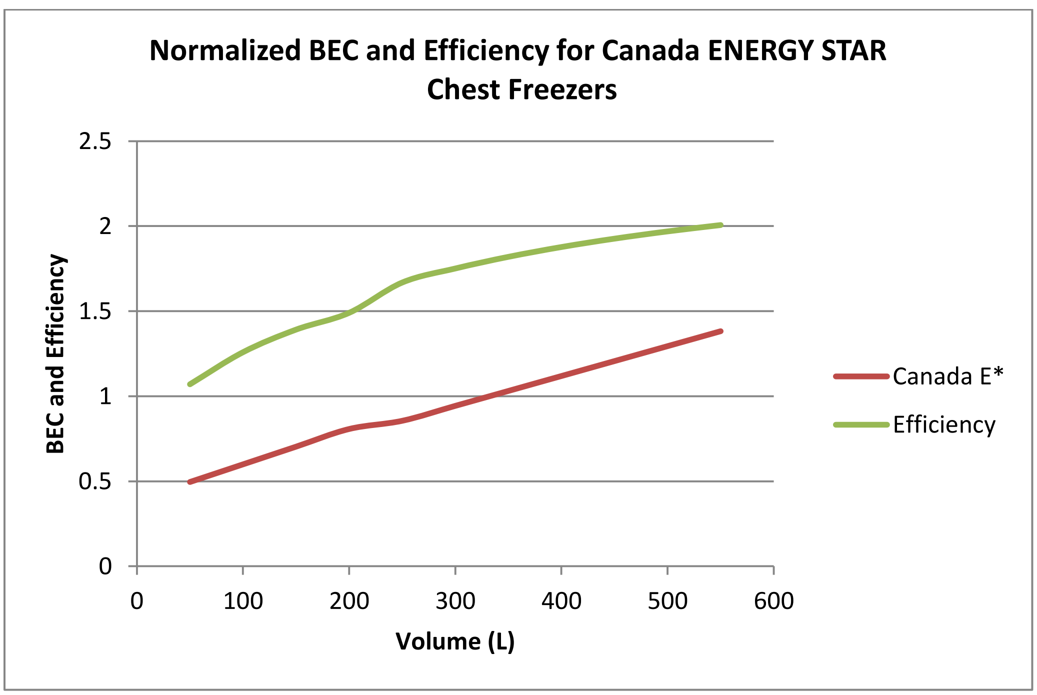
Figure 31 Normalized BEC and Efficiency for China Grade 1 Chest Freezers



It can be seen that China's Grade 1 level implied efficiency in general are about half as high as the UK's A^{+++} grade of chest freezers.

Finally, the normalized efficiency levels corresponding to the Canadian ENERGY STAR level of performance for chest freezers is presented on Figure 31.

Figure 32 Normalized BEC and Efficiency for Canada ENERGY STAR Chest Freezers



The normalized efficiency levels corresponding to the ENERGY STAR classification are generally lower than the top-rated levels in both China and the UK.

A summary of the normalized efficiency of freezers that are top-rated in each economy (over the range from 50 L to 550 L volumes) is presented on Figure 32 and on Table 25.

Figure 33 Comparison of Normalized top efficiency levels vs. Volume - UK, China and Canada

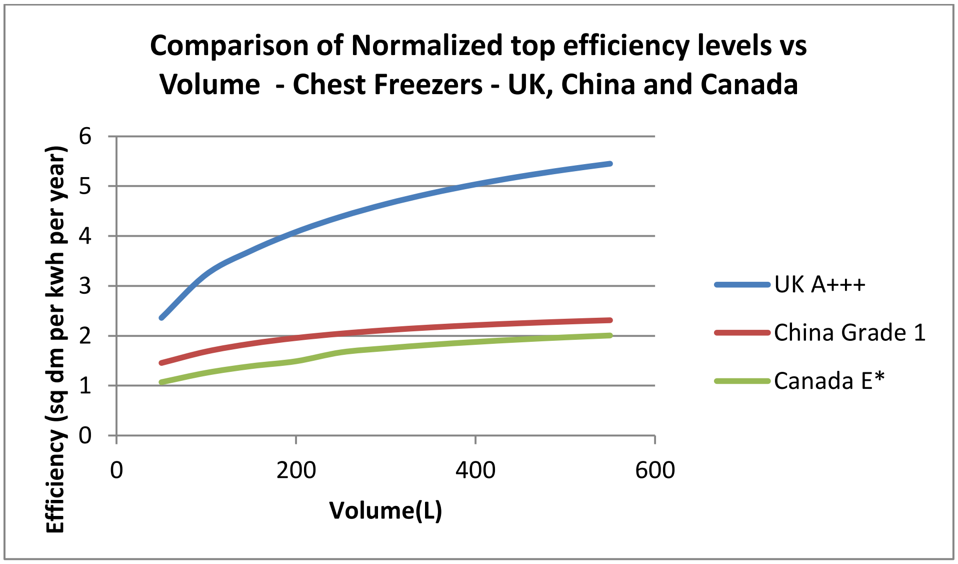


Table 25 Normalized Efficiencies of small volume and large volume Chest Freezers at the Base Level and at the highest performance level for the UK, China and Canada

	Chest freezer Volume		Ratio of efficiency levels by Unit Volume (550L/50L)
	50 L	**550 L**	
UK MEPS level	0.41	2.73	6.66
UK Highest level A+++	2.36	5.45	2.31
China Base Level (MEPS)	0.73	1.16	1.59
China Highest level Grade 1	1.46	2.31	1.58
Canada Base level (MEPS)	0.86	1.54	1.79
Canada Highest level ENERGY STAR	1.07	2.01	1.88

The implied efficiency of the UK's MEPS level increases very rapidly with total unit volume and is higher than that of both China and Canada for all but the smallest volumes.

The normalized efficiency level of the UK's A+++ grade of freezer is much higher than the efficiency of China's Grade 1 level and Canada's ENERGY STAR levels for both small freezers and large freezers.

Annex 3 Testing plan: description and sampling

A3.1 Description of the full range of product types for selection of samples to be tested

Testing to China and to UK Standards

Assuming that a round-robin testing of refrigerated appliances made in China will be conducted between China and the UK, this section will deal with the recommended choices for standards to be used and for product characteristics to select from.

The review of the Chinese standards applicable to refrigerated appliances of type 4, 5 and 7 indicated that the test conditions of the corresponding products are equivalent to the test conditions of the standard currently in use in the UK and the EU, Standard EN ISO 15505:2005. There are minor differences in the loading of the freezer section (refer to Tables 2 and 3 for details).

Testing refrigerators and freezers by laboratories involves selecting a facility that has been properly accredited by the nation's Standards Body to conduct the tests according to the **EN ISO 15505:2005** standard in the case of the UK, and according to China's standards **GB/T 8059.2-1995, GB/T 8059.3-1995 and GB/T 8059.4-1993**. There are most likely test labs in other countries as well as in the UK that are accredited to test to standard **EN ISO 15505:2005.** A practical choice would be to select 4 particular appliances for the tests, have them first tested in China and keep the initial test reports confidential; next, have the same appliances shipped to a laboratory accredited to test the same appliances to standard **EN ISO 15505:2005** and produce the normal reports**.** The test laboratory may be in the UK or much closer to Beijing. The results of both sets of test results would then be compared and analyzed for differences in results.

The selection of products should be representative of the most popular types, sizes and configurations of the four basic types of refrigerated appliances; please refer to Table 26

Table 26 Most popular sizes and features from a 2013 market survey/5/

Product Type	Most popular Volume range (L)	Configu-ration	Tier level	Number of doors	Defrost control	Through the door ice service	Free-standing or built in	Climate class
Type 4 refrigerator-freezers with no forced circulation	200-250	Bottom freezer	1	2 or 3	automatic	none	Free-standing	SN,N,ST
Type 5 refrigerator-freezers with forced circulation	190-200 and 430-490	Bottom freezer	1	2 or 3	automatic	none	Free-standing	SN,N,ST
Type 7 upright freezers with forced circulation	100-150	Upright	1	1	Frost-free	none	Free-standing	SN,N,ST
Type 7 chest freezers with no forced circulation.	175-225	Chest	1	1	manual	none	Free-standing	SN,N,ST

It is recommended that one of each of the product types outlined in Table 26 be selected for the round-robin testing. The tests in China can be used not only to set the targets to be met via the test of the same units done according to the UK standard, but also as a check on the accuracy of the product specifications sheet produced by the manufacturer. If significant differences in results are observed, matching up the freezer load should be planned as a potential extra test.

Testing to China and to Canada's Standards

The nature of this round-robin test would be more exploratory than comparative of accuracy of measurement of the 24-hour consumption tests in each economy for each product. The reason is that there is no unique and predictable correlation between test results of tests conducted on a particular product at different ambient and different controlled temperature conditions. Differences in the way that compartment temperature controls operate from one model to the next, limit the ability to precisely control temperatures individually in each compartment, often resulting in freezers having to operate at much colder temperatures in order to meet the fresh food compartment minimum required temperature, thus affecting energy consumption in an unpredictable way. This is the reason that normally two tests need to be conducted on every refrigerator at different controlled temperatures and the results need to be interpolated to estimate consumption at the desired target compartment temperatures. Different designs of appliances result in different relationships between freezer and fresh food temperatures as the temperature control settings are changed.

A3.2 Statistical sampling to be used in order to test the correlations developed

The round-robin test is a special case of refrigerated appliance testing. There will be no other models available for testing in case the test results of the 24-hour energy consumption test for each particular model is not within 15% of the claim made by the manufacturer and listed on the product specifications sheet. Naturally, the accuracy of the test results should be checked by the Verification Body that would normally interpret and check the test results against the requirement or claims made in the product specifications sheet.

Annex 4. Method Used to Calculate Internal Surface Area of refrigerator-freezers and Freezers

A product specifications sheet for refrigerated appliances does not normally list the internal surface area of each compartment. For the purpose of estimating interior surface area of fresh-food and frozen food compartments, the following method was developed. The method lends itself to being used on a single line of a spreadsheet, making it possible to automatically estimate the surface area from the external dimensions and compartment volumes of a refrigerated appliance.

1. We start with the measurement of total capacity, freezer capacity and fresh food capacity, annual consumption, external width, depth and height. Convert lengths to dm, volumes to L.
2. Next, twice the estimated thickness of insulation (0.59 dm) is subtracted from the external width and depth, so as to estimate the internal width and depth dimensions. Internal height is calculated at the next step.
3. The internal width, internal depth and <u>total</u> refrigerator (specified) volume are used to calculate average internal height. This average internal height will be smaller than the measured internal height at the front of the compartment because of the volume taken up by the refrigeration equipment below the rear of the lower compartment, usually in the shape of a step or a slanted surface.
4. Next, for a refrigerator-freezer, the individual internal height of the freezer and of the fresh food sections are calculated according to the freezer and refrigerator volumes, assuming the internal width and depth estimated in step 2. At this point, we will have the estimated internal width, depth and height of the fresh food and of the freezer sections.
5. Next, for a refrigerator-freezer, the individual interior surface areas of the freezer and fresh food sections are calculated, assuming only 5 surfaces for each, with the common surface between the freezer and fresh food sections omitted. For a single compartment freezer or refrigerator, the surface area of the 6-sided shape is calculated.
6. Next, the freezer surface area is "adjusted" according to the ratio of temperature differences between (ambient - interior of freezer) divided by (ambient – temperature of fresh food section).
7. Finally, the estimated fresh food compartment surface area and the *adjusted* freezer compartment surface area are added together to produce the total adjusted surface area of the appliance.
8. The *Efficiency* of the appliance can then be calculated by dividing the total adjusted surface area of the appliance by the claimed annual energy consumption in units of sq.dm per kWh per year.

The linear regression formulae relating surface area to volume were obtained from plots of volume vs adjusted surface area for each type of appliance (based on a random sample of products in the market in China) and are listed below:

Type 1: Volume = 1.2977 x adjusted surface area - 59.14

Type 4: Volume = 1.0753 x adjusted surface area - 97.47

Type 5: Volume = 1.1642 x adjusted surface area -133.83

Type 7 upright: Volume = 0.7121 x adjusted surface area - 75.093

Type 7 chest: Volume = 1.6108 x adjusted surface area - 68.248