Performance Data Normalisation Methodology for Professional Storage Cabinets

DRAFT Version 0.5: 15 June 2012

Contents

1. Introduction

This document describes the methodology used to normalise product performance data for professional storage cabinets to render it comparable. The normalisation was done in order to estimate the spread of market performance in the EU. This work was done in support of the eco-design regulation impact assessment study in May 2012.

2. Sources of data

The data sets made available are characterised in Table 9 on page 24. This includes data for over 2,300 cabinets of which just under half is from the EU (before removal of duplicates). Data has been obtained from the following sources for analysis:

a) CECED Italia data set. Claimed to be representative of the whole Italian market. Supplied directly by CECED Italia.

b) UK Enhanced Capital Allowance (ECA) scheme database. Only better performing models of certain types of product. Downloaded from ECA scheme web site[1] using 'compare details' settings to yield maximum data fields.

---

[1] See http://etl.decc.gov.uk/etl/find/

c) Danish energy-saving scheme[2] database. Better performing models of certain types of product, but which are estimated to account for 80% of Danish sales of these types of cabinet.

d) US ENERGY STAR database (Commercial Refrigerators & Freezers[3], selecting only solid door reach-in cabinets). Generally representative of the top 30% to 40% of the US market (no ENERGY STAR market penetration data are publicly available for commercial refrigeration products).

e) US California energy commission database[4] (Commercial refrigerators, selecting only solid door cabinets). California has performance requirements for these products and so performance may be higher than for the US as a whole.

f) Canadian federal commercial fridges and freezers product database from Natural Resources Canada. This is fully representative of products sold onto the Canadian market.

g) EU manufacturer data set. This represents some mainstream products from two suppliers.

3. Screening data sets for only products within scope

Some of the datasets included products that are not within the scope of the proposed eco-design regulation. These were screened out so that they would not skew average results.

The following criteria were used to screen datasets, all cabinets were **removed** that contained the following descriptors:

- ‘Open’
- Having no doors
- Having transparent or glass doors
- Having mixed (solid and glass doors)
- Roll in cabinets
- Pass through cabinets
- Buffet Table
- Display Case
- Ice Cream Cabinet
- Preparation Table
- Roll-In and roll-through
- Work-Top Table

Removal of duplicate products within each separate database was considered – i.e. products for which energy performance, net and gross volume, temperature class, key dimensions and product type are the same. Removal of these might ensure that rebadged products (identical products sold under different brand names) and representative models do not unduly skew averages, but it is also possible that such ‘duplicate’ models are sold under separate names and so give some approximation of a sales-weighted total (as no sales data were available for these products at all). The latter view was held strongly by those responsible for the CECED Italia data set. Hence duplicate models were left in all of the data sets.

Notes:

i. No lower limit of cabinet volume was imposed, products of all volumes were included.
ii. CEC data set contained only product labelled as Vertical – but height went down to 17 inches (430 mm) and so this includes under-counter cabinets and/or cabinets designed for placing on a counter.

[2] See http://www.savingtrust.dk/public-and-commerce/products/professional-white-goods
[3] http://www.energystar.gov/index.cfm?fuseaction=products_for_partners.showRefrigComm
[4] http://www.appliances.energy.ca.gov/AdvancedSearch.aspx

4. Normalisation steps to be carried out

1.1 The baseline test method

All data is to be normalised to a state as if carried out to the **CECED Italia test methodology**[5] which is a testing protocol based on EN ISO 23953-2:2006 with:

- Testing chamber at climate class 4 (30°C and 55% RH).
- compliance with temperature classes L1 and M1
- Door opening scheme for all **chilled** cabinets (and **counter freezers**):
  - Door opened for 2 minutes
  - Each door opened for 6 sec, 6 times per hour, for a total of 12 hours
  - Doors closed for 12 hours (less 2 mins)
- Door opening scheme for **vertical freezer** cabinets:
  - Door opened for 1 minute
  - Each door opened for 6 sec, 6 times per hour, for a total of 4 hours
  - Doors closed for 4 hours
  - First two steps repeated
  - Doors closed for 12 hours (less 2 min)
- Other differences in the CECED Italia method compared to EN 23953:2005 have not been analysed for this normalisation (e.g. calculation of internal volume).

Data are normalised to the CECED Italia methodology because it constitutes the largest EU dataset and so the maximum amount of EU data would remain un-adjusted. It is also likely that the final harmonised methodology will have much in common with this approach. If the harmonised methodology turns out to be significantly different then thresholds may have to be reviewed if they were based on this analysis.

1.2 Summary of steps to normalisation

The preferred route to normalisation for differences in test methodologies is according to a mathematical model of cabinet performance. This is designed to take account of the following aspects:

a) Door openings
b) Cabinet mean product pack temperature during test
c) Ambient temperature during test

Alternative routes to estimate b) and c) have also been identified for cross-checking against the model. These are also described in the relevant section.

Some data sets contain data derived from different test methodologies within the same data set.

The adjustments required are summarised in Table 8 on page 19.

1.3 Overview of the mathematical model

A lumped steady state empirical Excel-based model was developed to calculate total energy consumption of professional storage cabinets over 24 hours during closed door, EN441, EN23953, CECED Italia and ASHRAE 72 tests.

The model was initially developed to predict energy used by a typical 693 litre (internal gross volume) upright cabinet and was later extended to consider a 377 litre (internal gross volume) two-door under counter cabinet as a second model. In all cases (regardless of the measurement

[5] Test protocol for professional refrigerators and freezers, available from http://www.ceceditalia.it/servlet/poba_bwffile?p_NodoID=6138, accessed 19 May 2012.

method) energy was calculated over a 24 hour period and compared to test data over the same period. The data inputs to the model are summarised in Table 1

The model was compared against available test data and was then extended to consider a range of upright and under counter cabinet sizes.

The model calculated heat extracted by the refrigeration system and included:

1. Transmission across the cabinet insulation
2. Fans (evaporator)
3. Defrosts (freezers only)
4. Cabinet gasket (transmission only)
5. Door openings (infiltration)
6. Heat gain to test packs during the initial 1, 2 or 3 minute door opening period

The efficiency that heat loads were extracted by the refrigeration system was assessed by an assumed COP (coefficient of performance) for the refrigeration system. COPs were based on typical values calculated for freezers and chillers and then adjusted during the model fitting.

Auxiliary energy consumption fixtures were calculated and added to the energy used for heat extraction:

1. Fans – evaporator and condenser
2. Defrosts (freezers only)

As lighting is rare in professional cabinets it was ignored and energy used by controllers was ignored as it is low.

The resulting proportions of total consumption attributable to each of those sources is shown in Figure 1 and Figure 2.

1.4 Verification of the model

The model has not been exhaustively verified due to limited resources and time to complete the analysis. However, the following can be taken into account in this regard:

a) The energy consumption predicted by the model for an upright and a counter cabinet are shown in Figure 3 and Figure 4. The form and relative positioning of results fit with intuitive expectations of the experts involved.

b) The Canadian and US data sets, plus some limited specific performance data from tests of a few cabinets tested to different methodologies[6] were used to verify that the results given by the model appear reasonable and for refining the parameters to fit the available data. Figure 5 shows how the model results compare to the spread of product performance data for ASHRAE 72 tested products - the fit appeared reasonable.

c) The proportion of energy usage causes graphs (shown in Figure 1 and Figure 2) were discussed with engineering managers from three manufacturers to gauge results against their expectations. The energy arising due to door openings had a lower proportion than expected so this was further investigated (see next point). No other aspects gave cause for immediate concern.

d) A known weakness of the model is the heat assumed to be taken up by the test packs whilst the door is open. This is based on empirical measurements of the temperature rise of the packs during openings, but the probes are at the centre of the packs and heat will not be uniformly distributed in that time. Resolving this was too complex with the available time and resources but some additional tests on two chilled cabinets and one freezer cabinet were done to investigate the net heat gain during various door opening regimes. This has

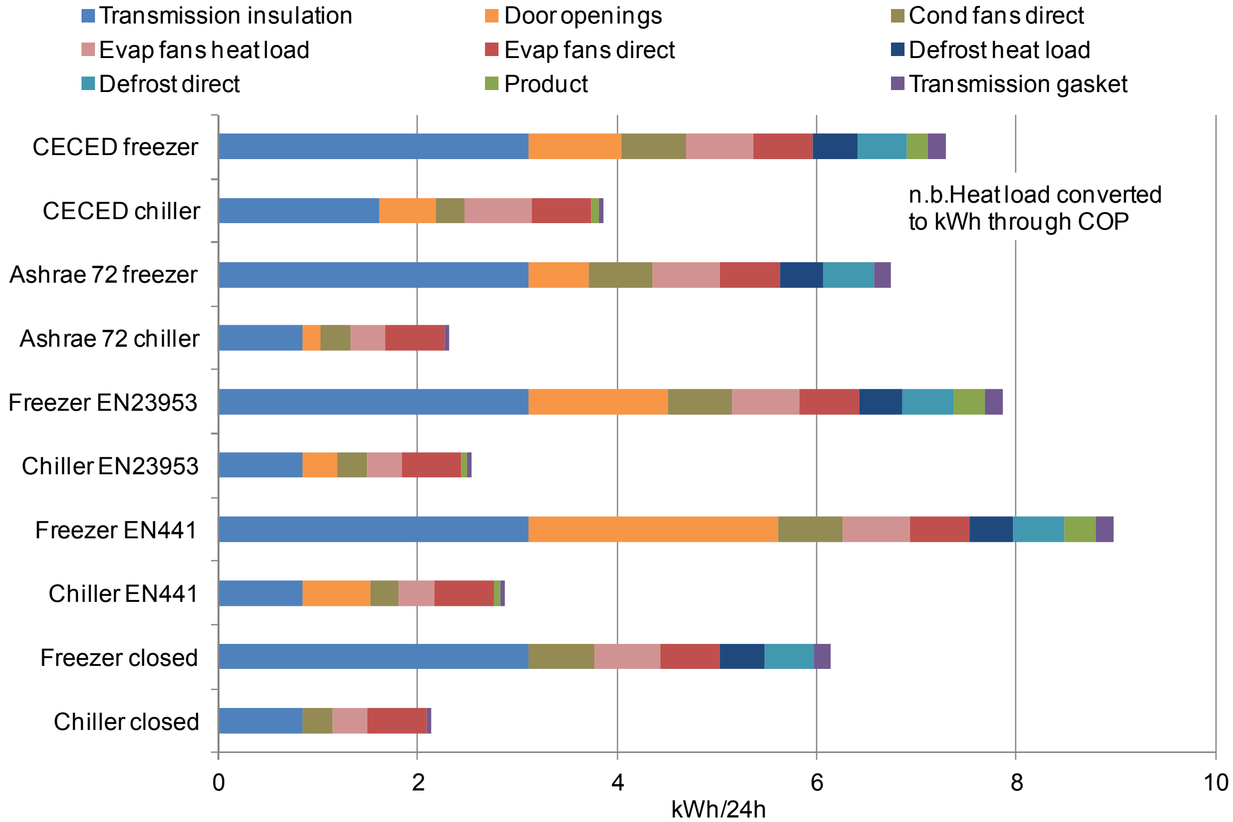
[6] Results provide by the Danish Technological Institute and by one manufacturer.

given some limited evidence that the model is under-predicting the proportion of energy attributable to door openings by up to 19% for these cabinet types. Since the energy arising from door openings accounts for between 8% and 27% of total energy according to model predictions. Therefore the total energy consumption *may* be around 6% higher[7] than the model predicts as a result of this error. This is appreciable but no correction was made for this.

e) The tests on two chillers and one freezer cabinet will also provide some limited verification of the overall accuracy of the model energy predictions. This is yet to be assimilated.

[7] Adding 19% of 27%.

Figure 1. Model outputs, showing two views of the same data of proportion of total energy consumption for an *upright cabinet* attributable to certain sources, for freezer and chilled cabinets tested according to various test methodologies. First view in kWh/24hrs, second as a percentage.



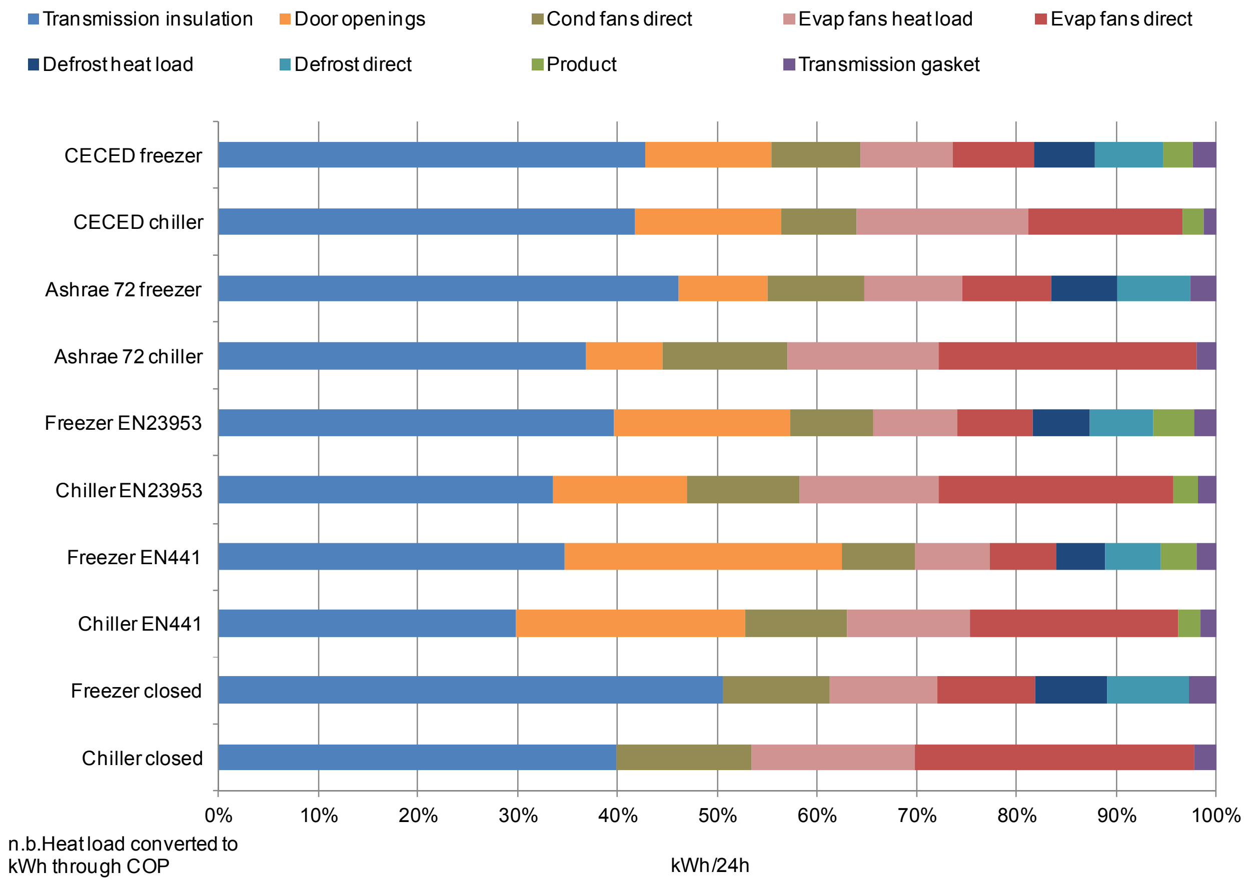
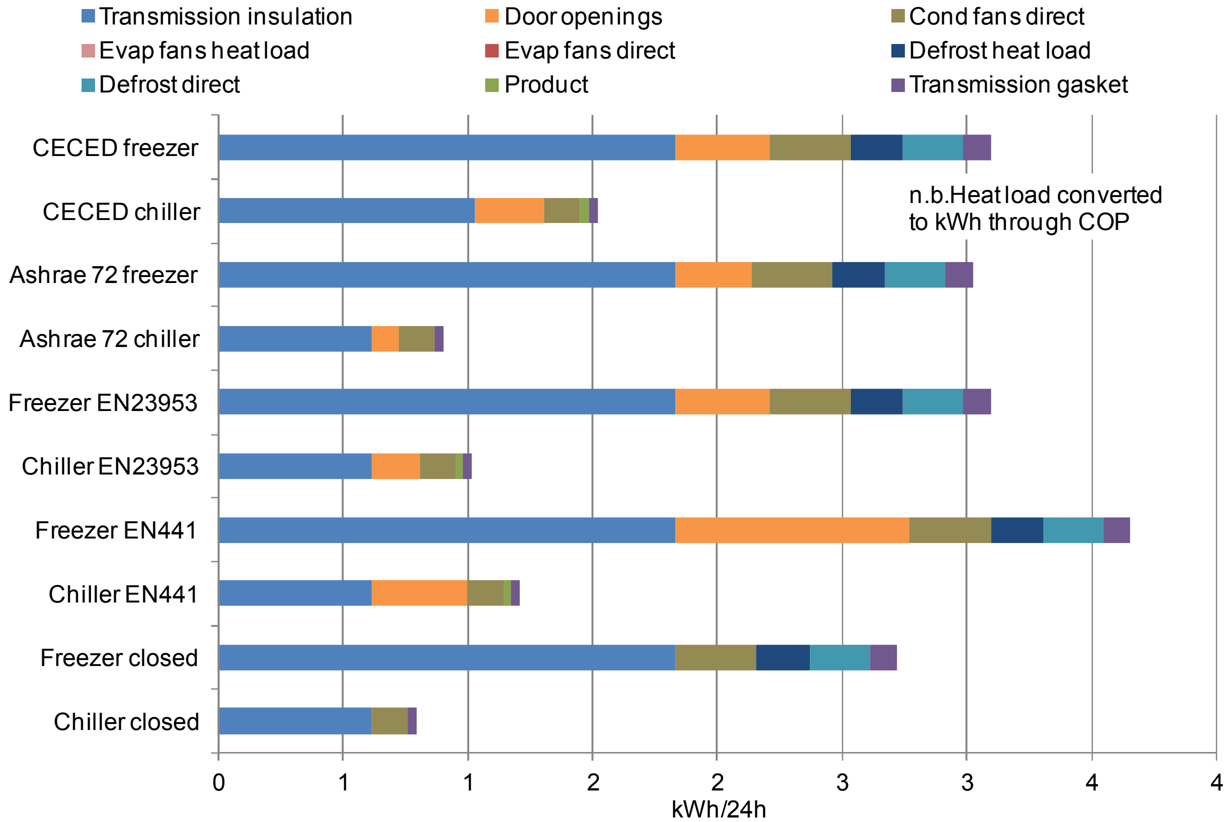


Figure 2. Model outputs, showing two views of the same data of proportion of total energy consumption for a counter cabinet attributable to certain sources, for freezer and chilled cabinets tested according to various test methodologies. First view in kWh/24hrs, second as a percentage.



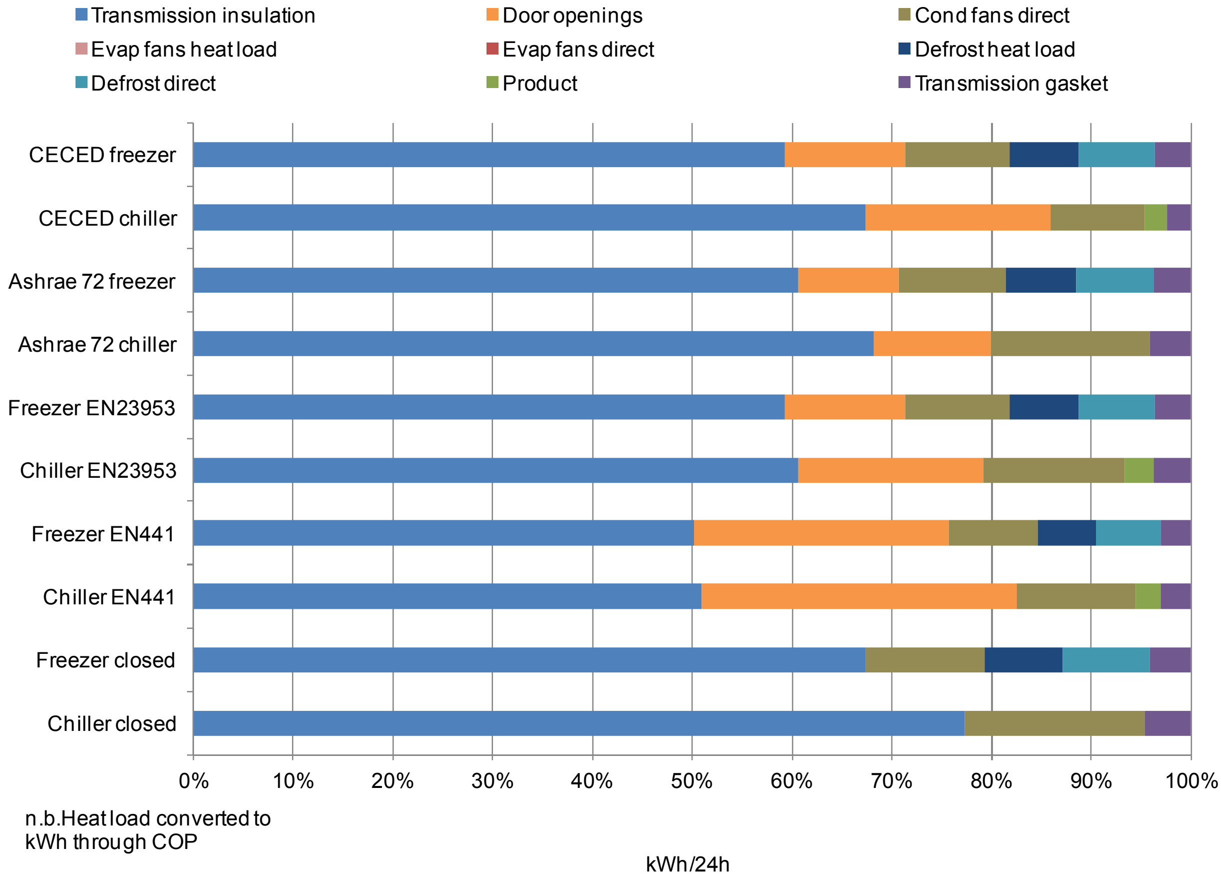


Table 1. Data inputs to the model.

	Units	Upright chiller	Upright freezer	Under counter chiller	Under counter freezer
Height	m	1.6	1.6	0.7	0.7
Depth	m	0.8	0.8	0.7	0.7
Width	m	0.8	0.8	1.0	1.0
Insulation thickness	m	0.055	0.055	0.055	0.055
k for PU	W/mK	0.025	0.025	0.025	0.025
ho	W/m2.K	7	7	10	10
hi	W/m2.K	10	10	10	10
k for Polyurethane rubber	W/mK	0.290	0.290	0.290	0.290
Specific heat capacity of air	kJ/kg.K	1.005	1.005	1.005	1.005
Density of chilled air	kg/m3	1.28	1.28	1.28	1.28
Density of frozen air	kg/m3	1.41	1.41	1.41	1.41
Weight 1m3 of chilled air	kg	1.28	1.28	1.28	1.28
Weight 1m3 of frozen air	kg	1.41	1.41	1.41	1.41
dT chilled	K	27	27	28	28
dT frozen	K	52	52	50	50
Latent heat of water-condensation	kJ/kg	2260	2260	2260	2260
Latent heat of water-fusion	kJ/kg	334	334	334	334
Water content of air at CC4	kg/kg	0.0154	0.0154	0.0154	0.0154
Water content of air at 3°C	kg/kg	0.0050	0.0050	0.0050	0.0050
Water content of air at -22°C	kg/kg	0.0010	0.0010	0.0010	0.0010
Evaoporator fan	W	25	25	0	0
Condenser fan	W	30	30	15	15
Run time (cond fan) chill	%	40%	40%	40%	40%
Run time (cond fan) freezer	%	90%	90%	90%	90%
Defrost heater (freezer only)	W	250	250	120	120
Specific enthalpy of tylose	kJ/kg.K	3.7	2.00	3.7	2.00
Weight test packs	kg	263	263	110	0
COP		1.70	0.90	1.50	0.90

Figure 3. Predicted energy consumption per cubic metre of net volume for an upright cabinet according to the different test regimes.

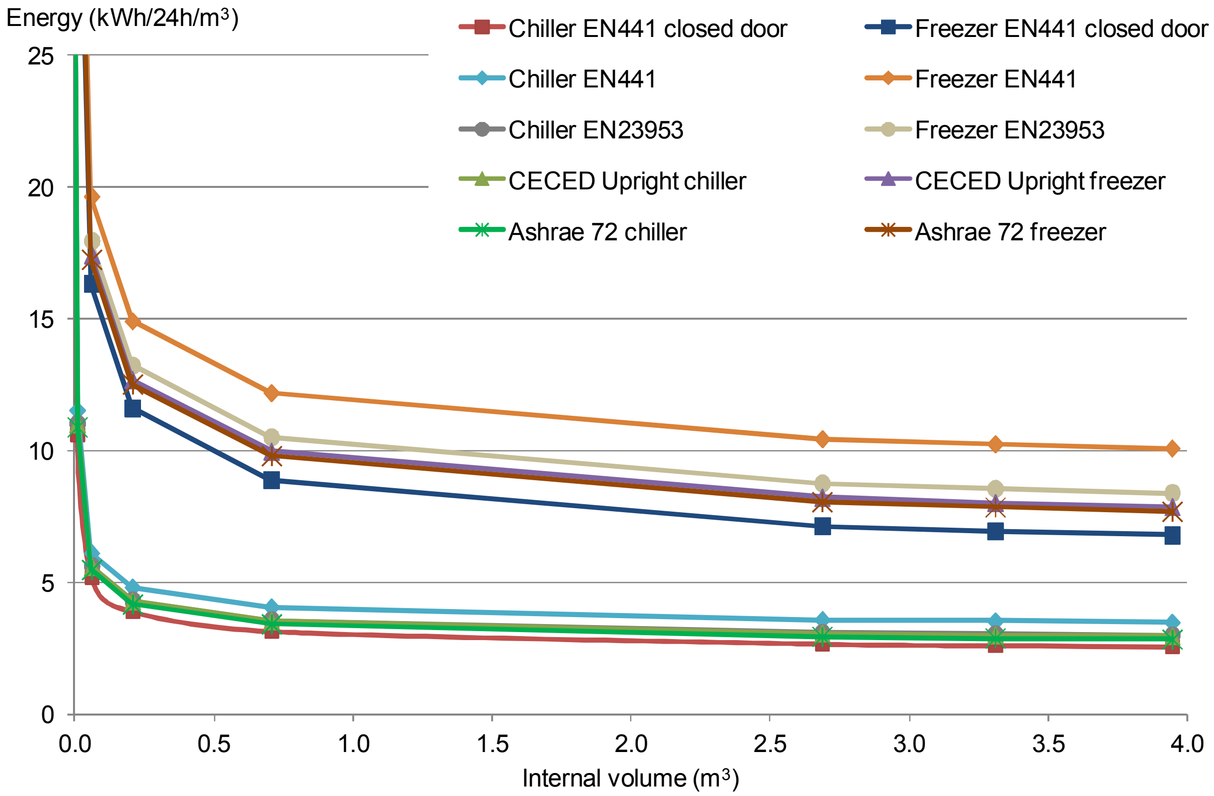


Figure 4. Predicted energy consumption per cubic metre of net volume for an horizontal cabinet according to the different test regimes.

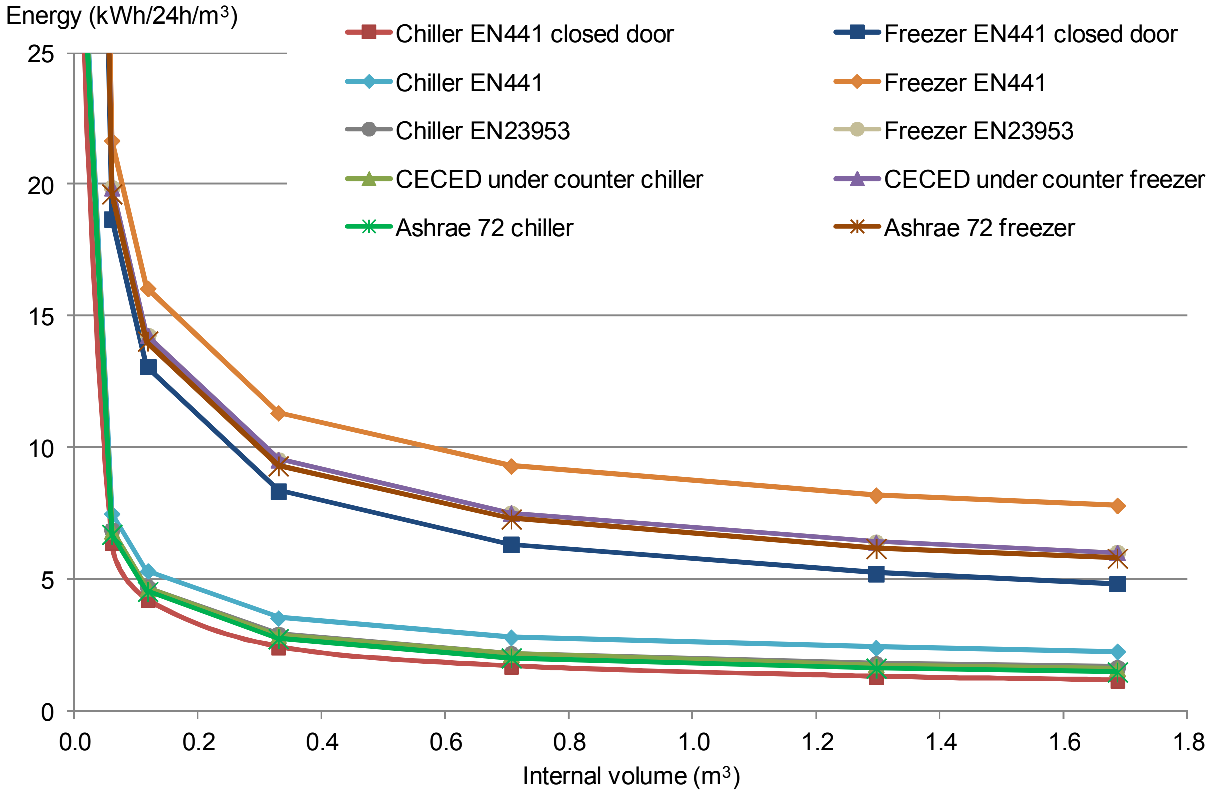
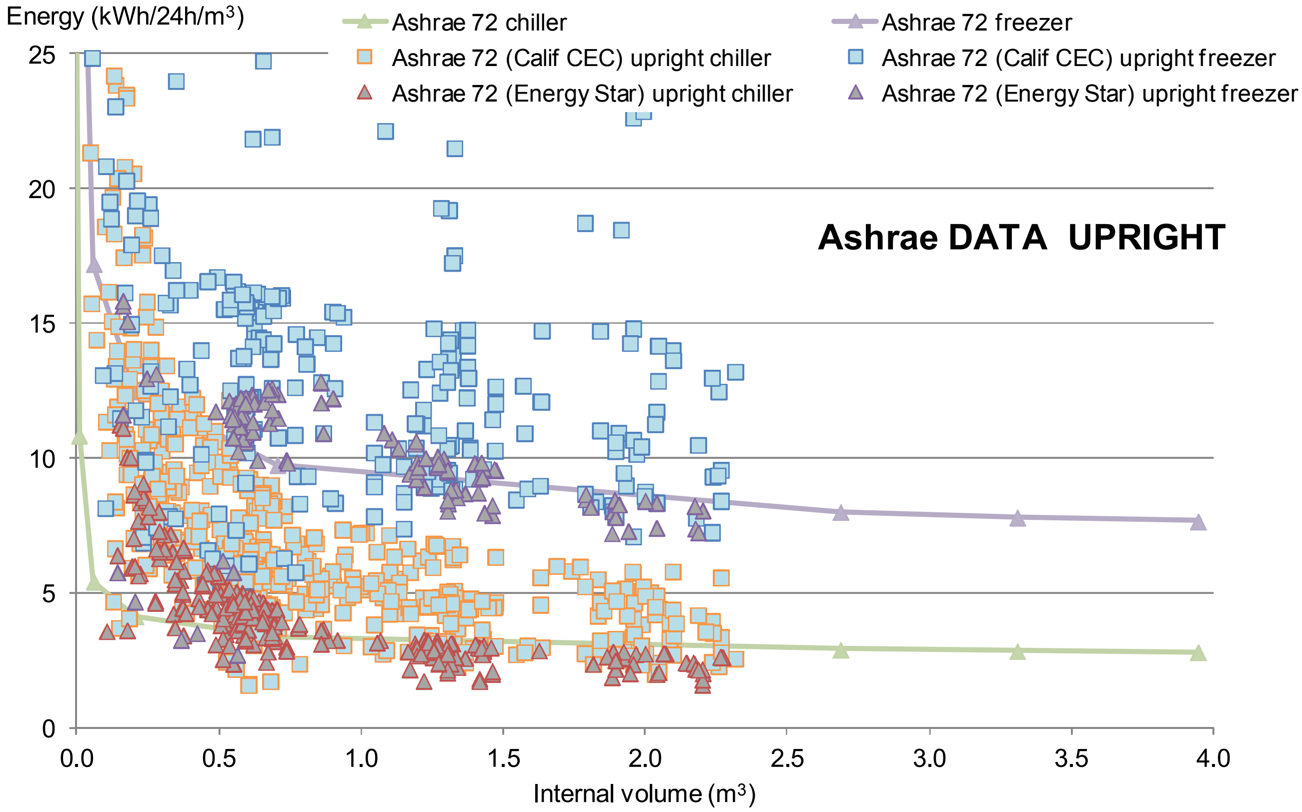


Figure 5. Graph showing how the spread of ASHRAE 72 test data compares to the predicted consumption from the model



1.5 Door openings during test

US, Canadian and European standards all require doors to be opened at specified intervals and for specified length of time during the test, totals for a single door cabinet are shown in Table 1. Cabinets with more doors would have staggered opening times and longer total times with any door open:

- The door opening regime for the ANSI/ASHRAE standard is over 8 hours requiring six seconds open every 10 min. The ANSI/ASHRAE standard does not include an initial 1 or more minute door opening which is part of other methods.
- Door openings occur over 12 hours in EN23953: 2005 with an initial three-minute door opening followed by 6 second door openings every 10 minutes.
- European standard EN441 (predecessor to EN23953) required door openings of 12 seconds every 10 min for 12 hours, including a three-minute opening at the start.
- CECED Italia for chilled and counter freezers:
  1. door opened for 2 mins
  2. each door opened for 6 sec, 6 times per hour, for a total of 12 hours.
  3. doors closed for 12 hours less 2 mins
- CECED Italia for vertical freezers:
  1. door opened for 1min
  2. each door opened for 6 sec, 6 times per hour, for a total of 4 hours
  3. doors closed for 4 hours
  4. 1 and 2 repeated
  5. doors closed for 12 hours less 2 mins
- An update to EN 23953 is currently in draft form and requires an initial 3 minutes opening of each door consecutively for all cabinets types. Then follows for chilled cabinets: Each door opened ten times per hour for 15 seconds over 12 hours; and for frozen cabinets each door opened 6 times per hour for 6 seconds over 12 hours.

Table 2. Total duration for which the door *on a single door cabinet* is open during 24 hours of testing for the different test methodologies.

Test method	Time for which the door is open per 24 hours of test for a single door cabinet (seconds)
No door openings (e.g. for household cold appliance tests)	0
ASHRAE 72-2005	288
EN23953: 2005	612
EN23953: 2012 (DRAFT) chilled cabinets	1,980
EN23953: 2012 (DRAFT) frozen cabinets	612
EN441 (superseded)	1044
CECED Italia chilled cabinets and counter freezers	552
CECED Italia vertical freezers	408

A rationale to enable normalisation for these differences in test method is based on a report[8] provided by Collaborative Labelling & Appliance Standards Program[9] (CLASP). This was based

[8] Support on Professional Cold (DG ENTR Lot 1) Impact Assessment: Report on normalisation of data between measurement methods, CLASP, 23 April 2012.
[9] See http://clasponline.org/

upon a product mathematical model calibrated using empirical evidence and provides a means to account for different periods of door openings.

Key limitations on the normalisation for door openings are:

1. The model is verified from a limited dataset.

1.6 Cabinet mean product pack temperature during test

From the available data sets there are two systems by which the cabinet temperature set-point, mean product pack temperature or class during a test may be described:

- EU data are defined in terms of temperature classes designated H1, H2, L1, L2 M1, M2 etc. Each class refers to a specific range of temperatures permitted during tests. The classes relevant to storage cabinets are L1 (frozen, <-15°C) and M1 (chilled, +1 to +5°C)
- USA ENERGY STAR and Canadian MEPS use test methodology ASHRAE 72 which defines an integrated average temperature with an associated tolerance which is 3.3±1.1°C for refrigerators and -17.8±1.1°C for freezer compartments. Note: a different temperature applies to ice cream storage since 2010[10].

For use during normalisation, integrated average temperatures for the EU temperature classes were defined based on empirical data[11]. These are summarised in Table 3.

Table 3. Indicative average temperatures found during testing on EU cabinets, tested according to EN23953.

EU temperature class	H1	H2	M1	M2	L1	L2
Indicative average temperature from testing (°C)	5.5	5.5	2.7	3.5	-26.0	-21.9

Table 4. Storage / test temperatures for the relevant test data

Data set / test method	Frozen temperature range	Frozen temperature integrated average for test	Chilled temperature range	Chilled temperature integrated average for test
EU EN441 and EN 23953 and CECED Italia methodology	L1, <-15°C	-26°C	M1, +1 to +5°C	3.5°C
ASHRAE 72, ENERGY STAR / Canadian MEPS	Frozen	-17.8°C	Chilled	3.3°C

These temperatures were applied via the mathematical model.

[10] Note: USA and Canadian test methodology ASHRAE 72 changed the storage temperature for frozen (ice cream) cabinets on 1/1/2010 from -21°C to -26.1°C. But note that this change had not been enacted in Canadian regulations (nor products data) at Spring 2011.
[11] From RD&T Ltd, Bristol, UK.

Key limitations on the normalisation for storage temperature are:

1. For the cross-checking route, the adjustment figures are based on performance of household appliances, not professional appliances. The impact of differences between the household and professional test methodologies on this aspect of performance could not be assessed.
2. Little data is available on the actual test temperatures used to derive the TEC figures for each cabinet –assumptions are made on the prevalent conditions in each data set.

Cross-check for the model via alternative route – storage temperature

For cross-checking with the model, an alternative route was selected: To multiply the temperature difference by a factor derived from empirical data.

The most robust source of this empirical data found is a report on international benchmarking of household cold appliances[12] published by the IEA Mapping and Benchmarking Annex[13]. This derives the necessary factors for percentage change of energy consumption for each degree difference of internal storage temperature from analysis of Australian household cold appliance test reports. The specific factors quoted here were based on analysis of over 400 test reports. Table 10 of that report (on page 21) provides adjustment factors for all types of household cold appliances. The relevant factors used in this analysis are shown in Table 5. There may be differences between the performance of household and professional cabinets in this regard, but no better source of these factors was identified and so these factors were used.

Table 5. Alternative route to cross-check with the model: Energy consumption conversion factors for differences in internal storage temperature.

Source product group for the factor (IEA 4E report Table 10)	Energy consumption difference factor, % per °C change from IEA4E report	Product type for which the factor is applied in this analysis
Group 1 (fresh food refrigerator without any freezer compartment)	**5%**	Chilled cabinets (all types)
Group 6U (vertical freezer cabinets with manual defrost)	5%	Not used (assumed that majority of professional cabinets have automatic defrost)
Group 7 (vertical freezer cabinets with automatic defrost)	**4.0%**	Freezer cabinets (all types)
Group 6C corresponds with horizontal chest freezers	**4.3%**	Chest freezers

[12] Domestic Refrigerated Appliances: International Comparison of Performance, April 2012, available from http://mappingandbenchmarking.iea-4e.org/news/cem-reports .
[13] IEA Implementing Agreement on Efficiency End Use Electrical Equipment (IEA 4E), see http://mappingandbenchmarking.iea-4e.org/.

1.7 Ambient temperature and humidity during test

The ANSI/ASHRAE tests are carried out with dry-bulb temperature of 24°C±1°C / wet-bulb 18°C±1°C (equivalent to relative humidity of around 55%). ISO EN 23593 includes several climate classes (see Table 6) and Climate Class 4 is the most widely used for testing of storage cabinets, including for the CECED Italia methodology.

The effect of having a different ambient temperature during test is increased because this type of cabinet often has a refrigeration system design that is subject to additional losses during the off cycle[14] (i.e. times when the compressor is turned off), the lower ambient temperature results in more time spent in off-cycle. No empirical evidence is available to quantify this additional effect.

Most USA and Canadian data is tested at conditions similar to climate class 3; most EU data was tested at climate class 4. Adjustment beyond one climate class adjacent to climate class 4 would probably result in significant inaccuracies. It was therefore decided to only adjust data tested in climate classes 3 and 5 and their close equivalents, and to deem data from tests at other conditions 'out of scope'.

Table 6. Ambient temperature and humidity climates classes as designated in EN23953, plus for ASHRAE 72 test conditions.

Test room climate class	Dry bulb temperature °C	relative humidity %	Dew point °C	Action carried out for normalisation
0	20	50	9.3	Deemed 'out of scope'
1	16	80	12.6	Deemed 'out of scope'
2	22	65	15.2	Deemed 'out of scope'
3	25	60	16.7	Adjust
4	30	55	20	Adjust
5	27	70	21.1	Adjust
6	40	40	23.9	Deemed 'out of scope'
7	35	75	30	Deemed 'out of scope'
8	23.9	55	143	Deemed 'out of scope'
As per ASHRAE 72	24	55	-	Adjust

The relevant ambient conditions were fed into the model to be included in the resultant adjustment factors.

Key limitations on the normalisation for ambient temperature are:

1. No definitive confirmation is included in the data sets on the actual ambient temperatures during tests used to derive the TEC figures for each cabinet – this is assumed for each data set.

Cross-check for the model via alternative route – climate class

For cross-checking with the model, an alternative route was selected: To multiply the temperature difference by a factor derived from empirical data. Very little empirical data could be identified to support adjustments for ambient temperature and humidity. Test data on three (chest) freezers

[14] These cabinets tend to use a capillary tube as an expansion valve and so vapour can creep back to the evaporator and form an additional heat load as it condenses there. The size of this load varies with the specific design of the system and no quantification is known at present. A lower test temperature could therefore penalise products using a simple capillary tube. This effect is avoided if a liquid line solenoid is fitted.

supported an indicative rule of thumb for 5% per degree centigrade difference, to be used alongside the standard rule of thumb of 2.5% per degree for chilled cabinets.

Equation 1
% adjustment to TEC for chilled cabinets = 2.5% x (ambient temp difference from 25°C)

Equation 2
% adjustment to TEC for frozen cabinets = 5% x (ambient temp difference from 25°C)

No alternative method to cross-check differences in humidity with the model could be identified.

5. Factors for which no normalisation is proposed

The following factors are assumed to be consistent and comparable between countries and test methodologies, and so ***no normalisation was carried out*** for these:

a) **Internal volume:** Methods to determine internal volume are not necessarily equivalent between test methods. Test methods used include: ANSI/AHAM HRF1-1979 "Energy, Performance and Capacity of Household Refrigerators, Refrigerator-Freezers and Freezers" (used to measure volume of closed refrigeration cabinets in USA); ISO EN 23593. The factor which makes most difference to the calculation of internal volume is how manufacturers interpret the text in the standards, which varies significantly[15]. Since no account could be taken of this, no adjustments are made for calculation of internal volume.

b) **Lighting regime:** No lighting is required in solid-door cabinets other than any which turns on when the door is open. Test methodologies have no difference in this regard.

c) **Product load package type.** The test methodologies require the refrigerated space to be loaded with test packages which simulate the presence of food/drink during test. Whilst there are differences in the type of package specified, these are assumed to make negligible difference to the market average efficiency results.

d) **Loading pattern of test packs within the cooled space.** This could make a difference to the airflow within the cabinet, particularly during door opening. However, no evidence was available from which to derive any adjustments and so this could not be done.

e) **Defrost.** The US and European test methodologies all require defrost to continue as pre programmed within the product during test. It is assumed that this is common to all relevant test methodologies and so no normalisation is required.

6. Outputs of the model

The model enabled the plotting of the 2 graphs show as Figure 6 and Figure 7. These graphs show the predicted energy consumption of cabinets under each methodology, and combine the model's predictions of differences in test methodology for door openings, ambient temperature and storage temperature. The graphs allow proportioning of the relative energy consumptions between the methodologies.

[15] Anecdotal evidence from product testing experts.

Figure 6. Graph of energy consumption per 24 hours against cabinet volume for counter cabinets according to different test methodologies, showing results from the mathematical model.

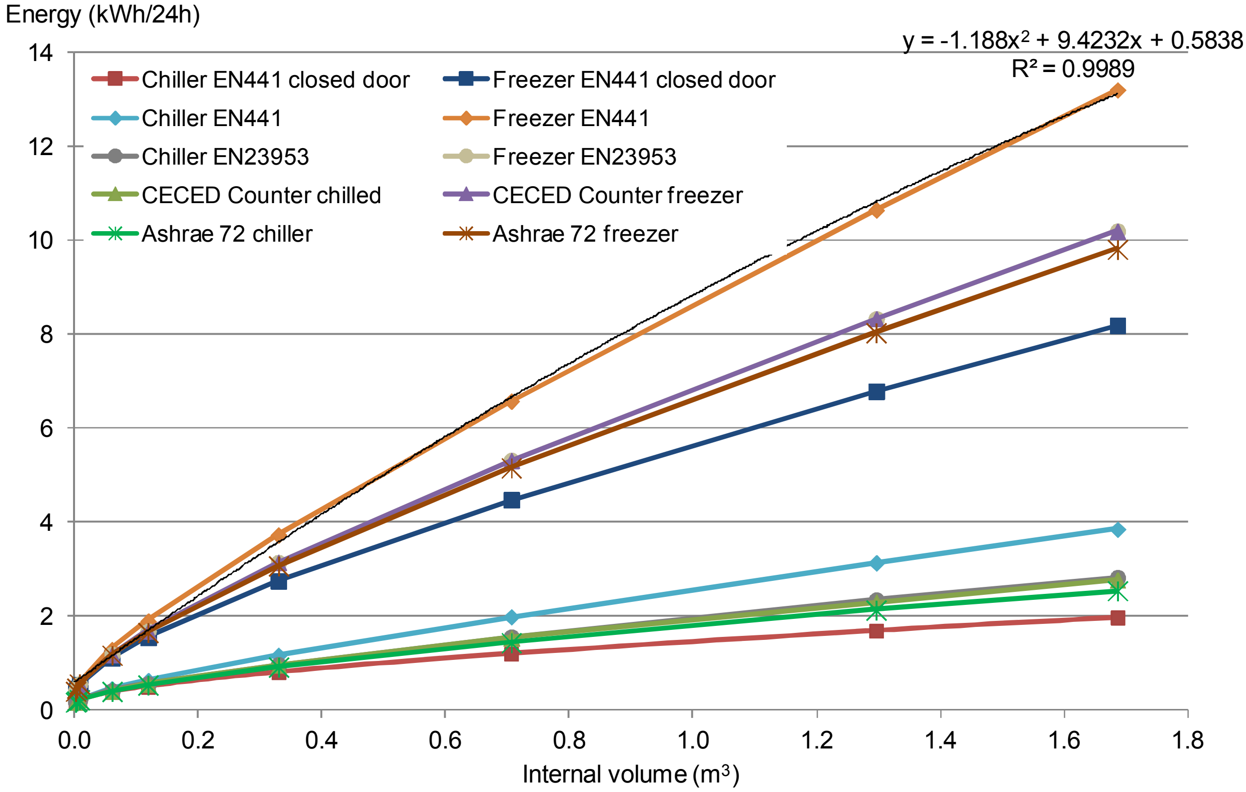


Figure 7. Graph of energy consumption per 24 hours against cabinet volume for upright cabinets according to different test methodologies, showing results from the mathematical model.

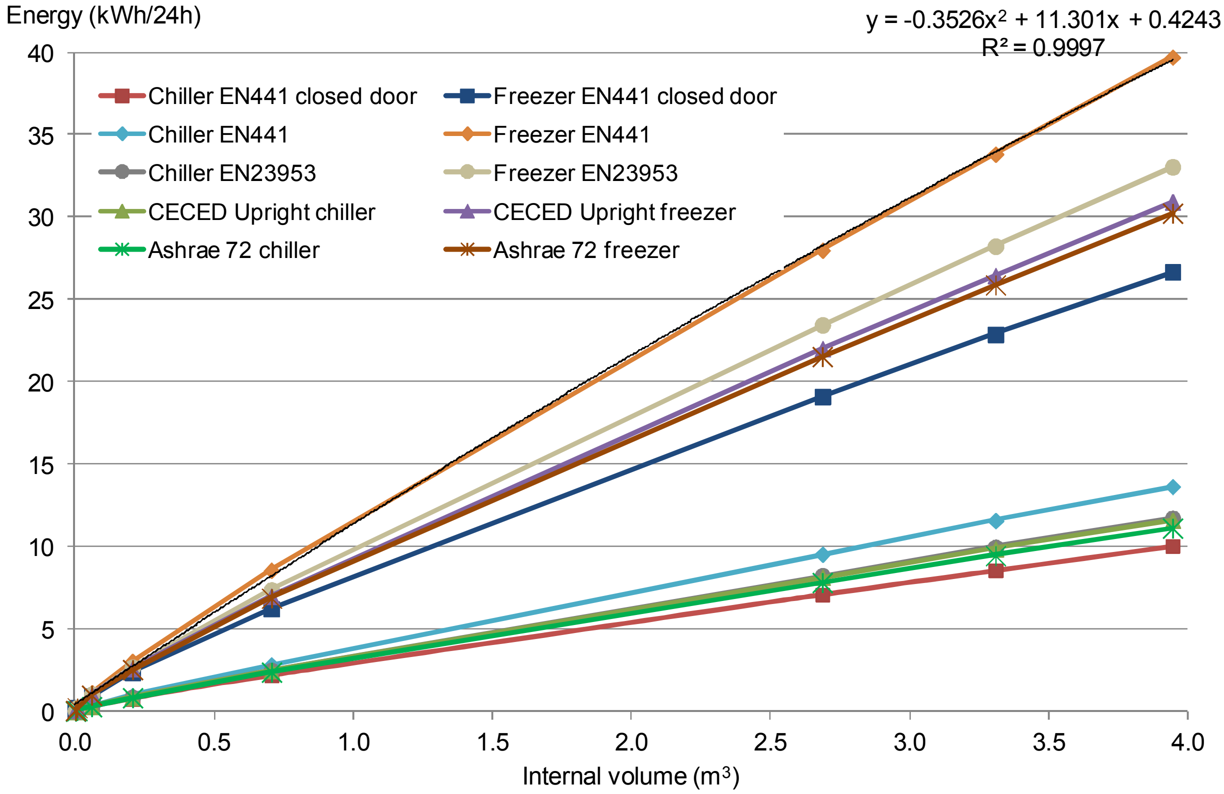
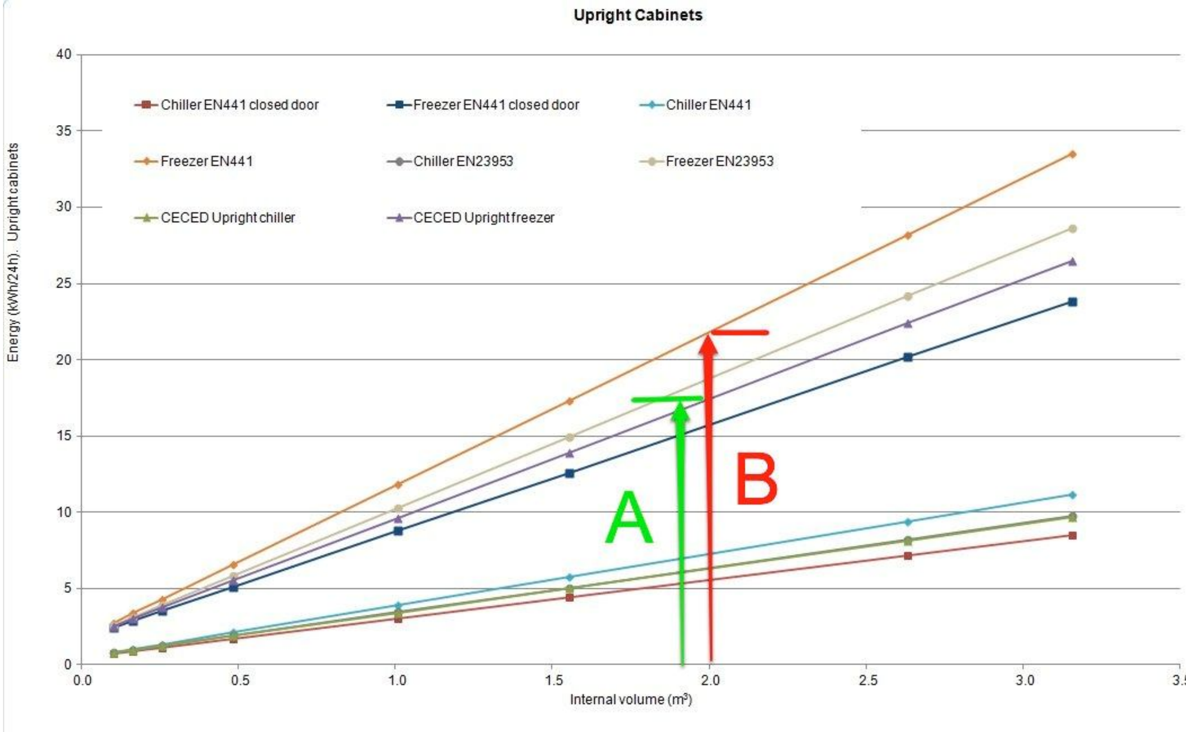


Figure 8. Example graph (similar to Figure 6) to illustrate how the graph is used to proportion energy consumption between different methodologies.



As an example calculation step: in Figure 8 the energy consumed by a 2 m^3 upright freezer cabinet tested according to EN441 is around 22 kWh (dimension B) per 24 hours; and for the same cabinet under CECED Italia 17.5 kWh (dimension A). So a test result under EN441 should be adjusted by the ratio:

Test result as if under CECED Italia = [Test result under EN441] x (A / B)

The curves of Figure 6 and Figure 7 were approximated to straight lines over a range of volumes approximately applicable to the product data in the EU data sets. Knowing the equations of each of the lines on the graph to calculate A and B for any given volume (see Table 7), and the net internal volume of the cabinets under test means that the appropriate ratios can be calculated. These can be applied to each energy result to adjust the measured energy consumption to be comparable to that under the CECED Italia method. The slope and intercept of these lines is shown in Table 7 and these were used to apportion the adjustments in energy results.

Table 7. Slope and intercept values for the graphs of Figure 6 and Figure 7.

Product type	Test method	m	c
CH	441	2.1588	0.3893
CH	239	1.5154	0.3893
CH	CEC	1.5154	0.3893
CH	ASH	1.3821	0.3893
FH	441	7.5158	1.054
FH	239	5.7316	1.054
FH	CEC	5.7316	1.054
FH	ASH	5.5042	1.054
CU	441	2.1588	0.3893
CU	239	1.5154	0.3893
CU	CEC	1.5154	0.3893
CU	ASH	1.3821	0.3893
FU	441	7.5158	1.054

FU	239	5.7316	1.054
FU	CEC	5.7316	1.054
FU	ASH	5.5042	1.054
CV	441	3.4765	0.2635
CV	239	2.9876	0.2635
CV	CEC	2.9554	0.2635
CV	ASH	2.8364	0.2635
FV	441	10.111	0.9584
FV	239	8.4266	0.9584
FV	CEC	7.8876	0.9584
FV	ASH	7.7144	0.9584

Table 8. Overview of the normalisation processes carried out on each data set – to make each set comparable to sets from other countries. No normalisation is carried out for ambient humidity (assumed negligible impact as only test results from climate classes 3, 4 and 5 or equivalent are included in scope).

Data set	Door opening	Storage temperatures	Ambient temperature during test
CECED Italia data set (baseline test)	No adjustment required	No adjustment required	No adjustment required
UK ECA	Required as per EN441 – adjustment required	Storage temp class L1 or M1 - no adjustment required.	ECA requires climate class 4 - no adjustment required.
Danish data set	Required as per EN441 – adjustment required	Storage temp class L1 or M1 - no adjustment required.	Scheme requires climate class 4 - no adjustment required.
[EU manufacturer]	Some data with EN441; some with EN23953 – adjustment required	Storage temp class L1 or M1 - no adjustment required.	No adjustment required
Canada	As for ASHRAE 72 – adjustment required.	Stated whether refrigerated (chilled) or freezer (frozen). Storage temps for freezer of -17.8°C (not ice cream) and +3.3°C for chilled. Adjustment required.	Assumed to be 24°C. Adjustment required.
US CEC	As for ASHRAE 72. – adjustment required	Stated whether refrigerated (chilled) or freezer (frozen). Storage temps for freezer of -17.8°C (not ice cream) and 3.3°C for chilled. Adjustment required.	Assumed to be 24°C. Adjustment required.
US Energy star	As for ASHRAE 72. – adjustment required	Stated whether refrigerated (chilled) or freezer (frozen). Storage temps for freezer of -17.8°C (not ice cream) and 3.3°C for chilled. Adjustment required.	Assumed to be 24°C. Adjustment required.

7. Normalisation of MEPS

MEPS and voluntary standards from several countries and schemes are to be plotted on the same scatter plot graphs as the normalised data. This section identifies the relevant performance levels. All were normalised using the same process as for performance data.

Figure 9. MEPS for chilled cabinets (note: ENERGY STAR line being checked, potential error)

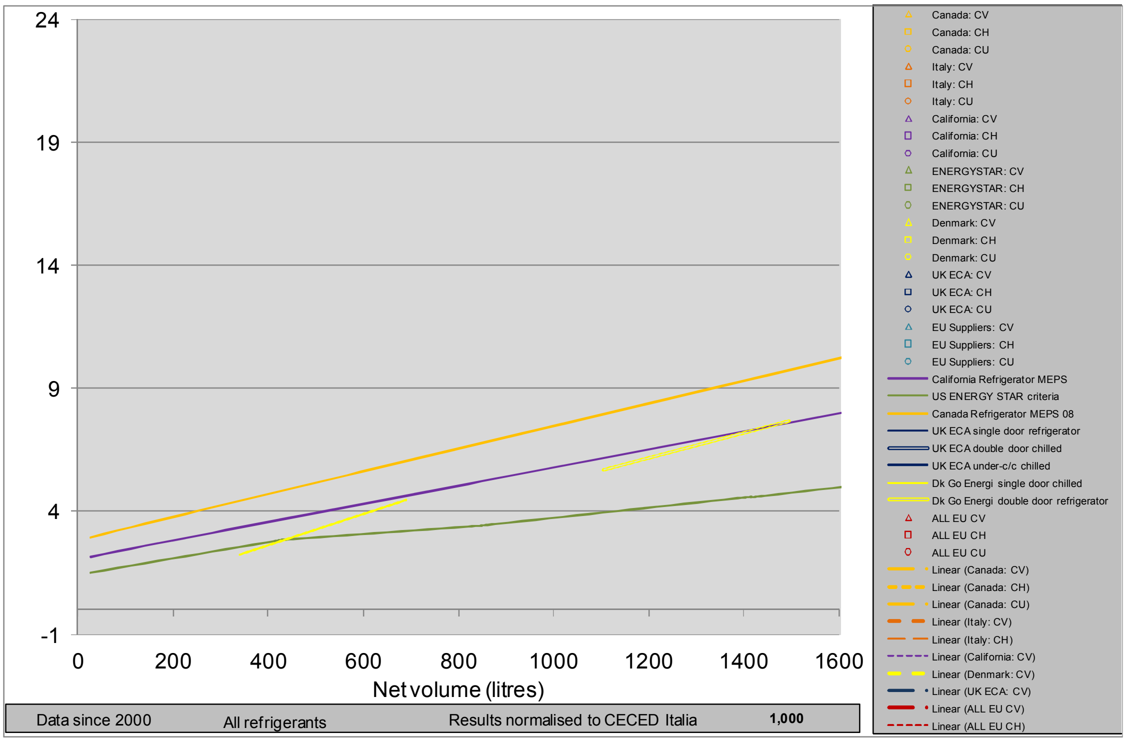
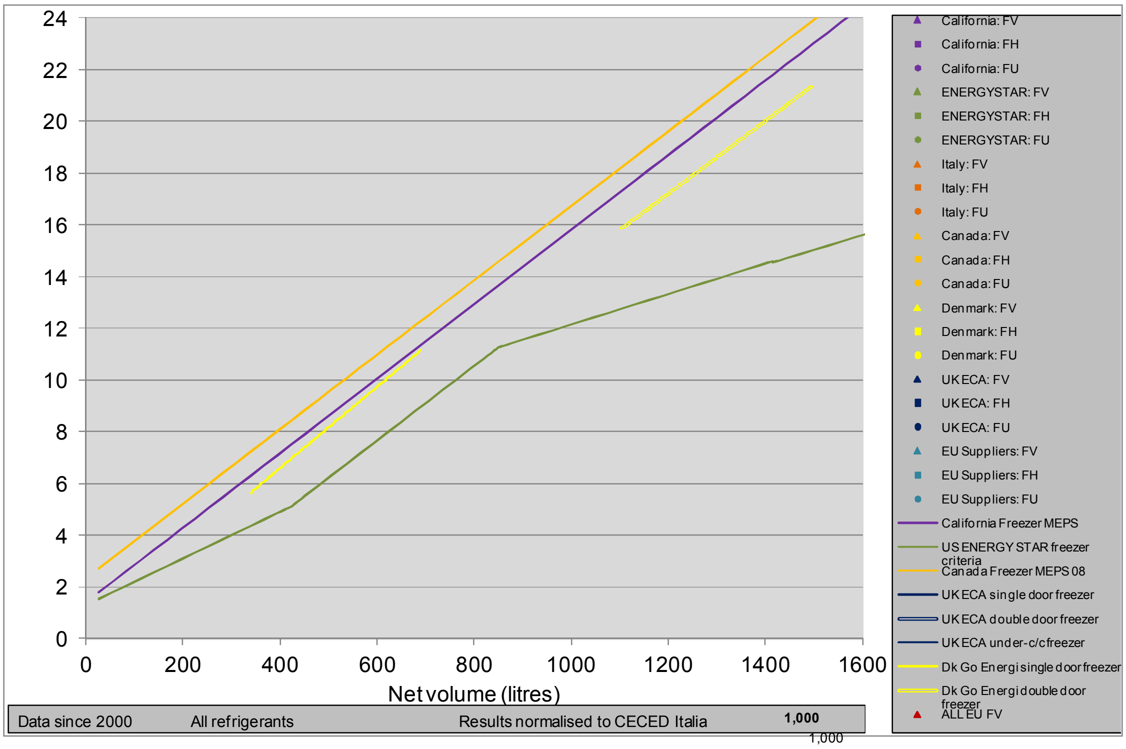


Figure 10. MEPS for freezer cabinets (Canada orange; California purple; Denmark yellow; US ENERGY STAR green).



1.8 MEPS for California

California Energy Commission, 2010 Appliance Efficiency Regulations, December 2010 CEC-400-2010-012, Table A-4 Standards for Commercial Refrigerators, Refrigerator-Freezers, and Freezers Manufactured on or After January 1, 2010. V is in cubic feet; MDEC in kWh per 24hrs.

Table A-4
Standards for Commercial Refrigerators, Refrigerator-Freezers, and Freezers Manufactured on or After January 1, 2010

Appliance	*Maximum Daily Energy Consumption (kWh)*
Refrigerators with solid doors	0.10V + 2.04
Refrigerators with transparent doors	0.12V + 3.34
Freezers with solid doors	0.40V + 1.38
Freezers with transparent doors	0.75V + 4.10
Refrigerator/freezers with solid doors	the greater of 0.27AV–0.71 or 0.70
Refrigerators with self-condensing unit designed for pull-down temperature applications	0.126V + 3.51

1.9 US ENERGY STAR criteria

Version 2.1 ENERGY STAR Program Requirements Product Specification for Commercial Refrigerators and Freezers, Eligibility Criteria Version 2.1. V is in cubic feet; MDEC in kWh per 24hrs.

3) Qualification Criteria:

A. Maximum Daily Energy Consumption Requirements:

Table 1: ENERGY STAR Requirements for Commercial Food-grade Refrigerators and Freezers

Product Volume (in cubic feet)	Refrigerator	Freezer
Vertical Configuration		
Solid Door Cabinets		
0 < V < 15	≤ 0.089V + 1.411	≤ 0.250V + 1.250
15 ≤ V < 30	≤ 0.037V + 2.200	≤ 0.400V – 1.000
30 ≤ V < 50	≤ 0.056V + 1.635	≤ 0.163V + 6.125
50 ≤ V	≤ 0.060V + 1.416	≤ 0.158V + 6.333
Glass Door Cabinets		
0 < V < 15	≤ 0.118V + 1.382	≤ 0.607V + 0.893
15 ≤ V < 30	≤ 0.140V + 1.050	≤ 0.733V – 1.000
30 ≤ V < 50	≤ 0.088V + 2.625	≤ 0.250V + 13.500
50 ≤ V	≤ 0.110V + 1.500	≤ 0.450V + 3.500
Chest Configuration		
Solid or Glass Door Cabinets	≤ 0.125V + 0.475	≤ 0.270V + 0.130

1.10 US MEPS

The US DOE Final Rule for commercial refrigerators and freezers[16] does not contain MEPS for self-contained solid door cabinets (only for self-contained open cabinets or solid door cabinets for ice cream).

[16] US DOE Part III, 10 CFR Part 431 Final Rule (January 9, 2009): Energy Conservation Standards for Commercial Ice-Cream Freezers; Self- Contained Commercial Refrigerators, Commercial Freezers, and Commercial Refrigerator-Freezers Without Doors; and Remote Condensing Commercial Refrigerators, Commercial Freezers, and Commercial Refrigerator-Freezers

1.11 Canada MEPS

From http://oee.nrcan.gc.ca/regulations/10392

Note:

V is the refrigerator volume measured in litres
AV (adjusted volume, in litres) is equal to the refrigerator
volume plus 1.63 times the freezer volume.
Edaily = Maximum daily energy consumption (kWh)

PRODUCT	TYPE OF CABINET DOOR OR CABINET DRAWER	MAXIMUM DAILY ENERGY CONSUMPTION (kWh)
Self-contained, commercial refrigerators	OPAQUE	**Jan. 1/07 to Dec. 31/07:** E_{daily} = 0.00441V + 4.22 **Effective Jan. 1/08:** E_{daily} = 0.00441V + 2.76
	TRANSPARENT	**Jan. 1/07 to Dec. 31/07:** E_{daily} = 0.00607V + 5.78 **Effective Jan. 1/08:** E_{daily} = 0.00607V + 4.77
Self-contained, commercial refrigerators or freezers	NO DOORS	**Effective Jan. 1/07:** No maximum daily energy consumption is specified. However, manufacturers still have to test their units, have the performance verified and report the value.
Self-contained commercial freezers	OPAQUE	**Jan. 1/07 to 31 Dec./07:** E_{daily} = 0.0141V + 2.83 **Effective Jan. 1/08:** E_{daily} = 0.0141V + 2.28
	TRANSPARENT	**Effective Jan. 1/07:** E_{daily} = 0.0332V + 5.10
Self-contained commercial refrigerator-freezers	OPAQUE	**Jan. 1/07 to 31 Dec./07:** E_{daily} = 0.00964AV + 2.63 **Effective Jan. 1/08:** E_{daily} = 0.00964AV + 1.65

Change from April 2005 proposal:

1. The term "reach-in cabinets, pass-through cabinets and roll-in or roll-through cabinets" has been changed to "self-contained commercial" units.
2. The regulations have been extended to include all self-contained commercial refrigerators and freezers without doors (and not just units that sell canned or bottled beverages.) No maximum daily energy consumption is specified, however manufacturers still have to report what the daily energy consumption is for these units with the

1.12 UK ECA scheme

Table 1 Performance thresholds for commercial service cabinets

Type	Gross internal volume (litres)	EEI performance threshold ($kWh/48hrs/m^3$)	
		Chilled (M1)	Frozen (L1)
Single door commercial service cabinets	400 and 600 (+/-15%)	<= 16.0	<= 38.0
Double door commercial service cabinets	1,300 (+/-15%)	<= 12.0	<= 34.0
Under counter and counter commercial service cabinets with solid doors or drawers	150 to 800 (+/-15%)	<= 21.6	<= 40.0

"<=" means "less than or equal to"

1.13 Denmark Go Energi scheme

- The product must conform to the demands on energy efficiency, which are measured as power consumption per cubic meter (m^3) net volume of the appliance per 48 hours. The unit is $kWh/48h/m^3$. To qualify for listing the relative power consumption should not exceed the figures shown below:
    - 400 and 600 litre fridges: 15 $kWh/48h/m^3$
    - 1300 litre fridges: 12 $kWh/48h/m^3$
    - 400 and 600 litre freezers: 40 $kWh/48h/m^3$
    - 1300 litre freezers: 36 $kWh/48h/m^3$

Table 9. Basic characteristics of the data sets. Not necessarily all of the cabinets counted here will be analysed as some will be deleted as duplicates.

Data set	Date of data set	Years covered	No of different manufacturer included	Test method	Total number of CHILLED cabinets	Total number of FROZEN cabinets	Total number of FRIDGE-FREEZER cabinets	Internal net Volume	Outer dimensions of cabinet (HxWxD)	Temp class	No of doors
[EU manufacturer]	May-12	2005-2012	2	EN441 and EN23953	*31*	*28*	-	y	n	L1; M1	n
CECED Italia	Feb-12	2009	4	CECED Italia variant of EN23953	*604*	*184*	*18*	y	y	L1; M1	y
Canada	Mar-11	2007-2010	25	ASHRAE 72 / ASHRAE 117	302	152	6	y	y	chilled; frozen	y
UK ECA	Jan-12	2004-2011	14	ECA criteria - based on EN441	134	61	-	y	n	L1; M1	n
Danish data set	May-12	2012	6	Danish Go Energi scheme criteria, based on EN441	24	18	-			L1, M1	
US CEC	Feb-12	1993-2012	30	10 CFR Section 431.64 (2008), which is based on ASHRAE 72	851	538	26	y	y	Freezer; refrigerator; fridge-freezer	n
US Energy star	May-12	not known	24	ENERGY STAR Criteria, based on ASHRAE 72	393	200	-	y	y	chilled; frozen	y
Total					2,339	1,181	50				