Support on Professional Cold (DG ENTR Lot 1) Impact Assessment

Report on normalisation of data between measurement methods

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ABOUT CLASP

Established in 1999, CLASP is an independent non-profit organisation serving as a resource and voice for energy efficiency worldwide. CLASP has provided technical assistance on standards and labelling (S&L) in over 50 countries, supporting and promoting energy-efficiency in appliances, lighting and equipment. In 2009, CLASP became a ClimateWorks Foundation (CWF) global Best Practice Network on S&L. CWF funding has enabled CLASP to expand its activities globally to reduce the emission of greenhouse gases that cause climate change. Currently, CLASP has offices or programmes in China, the European Union, India, Latin-American and the United States.

CLASP's primary objective is to identify and respond to the analysis needs of S&L practitioners in targeted countries and regions while making the highest quality technical information on S&L best practice available globally. To this end, CLASP works on the ground providing technical analysis and expertise to national governments and local partners; aggregates resources; assembles project teams from diverse and highly-qualified organizations; oversees projects; partners and collaborates with policy makers and members of industry alike; and disseminates information for maximum impact. This report was prepared for and provided by CLASP's Europe office as part of its effort to strengthen the European Commission's regulatory analysis on Professional Cold equipment.

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1. Introduction and Background

The European Commission is currently drafting an ecodesign Regulation, which will be setting minimum energy performance requirements) (MEPS) for professional (commercial service) cabinets. This report outlines the numerical approach CLASP developed for normalising professional cabinet performance data, taking into account differences in volume calculation methods and measurement methods (ambient temperature, cabinet internal temperature, door opening protocol, period of energy measurement and energy consumed by auxiliary features such as defrost, circulation fans, etc.).

CLASP retained Judith Evans, Refrigeration Developments and Testing Limited (RD&T), a renowned expert in professional refrigeration equipment, and particularly service cabinets, and a contributor to the elaboration of the methodology developed by the IEA 4E Mapping and Benchmarking Annex team for normalising retail display cabinet data.

The present report describes the proposed methodology developed to make all professional cabinet performance data comparable on a fair basis. The methodology, the data sources and the fitting of the model are presented in dedicated sections. The report also introduces two somewhat related issues that the Commission had brought to our attention. We expect that the Commission will consider whether more work should be done to elaborate on them: i) classification of cabinets and ii) representative testing (i.e. how bespoke cabinets can be tested and compared to others).

2. Normalisation between standard measurement methods used to test professional cabinets

2.1. Methodology

CLASP has carried out an assessment to compare energy performance of professional cabinets in closed door tests to the EN441, EN23953 and the new CECED[1] standard measurement method. In all cases the testing was carried out in climate class 4 conditions (30°C, 55% RH) and therefore a translation between test room conditions was not required.

A summary of the test regime for each of the standards is presented in Table 1. In all tests there is an initial door opening period (1, 2 or 3 minutes) followed by a shorter scheduled door opening regime. In EN441 the door openings are 12 seconds and in all other tests are 6 seconds. All shorter scheduled door openings are programmed for 10 minute intervals.

Table 1. Summary of test procedure for EN441 (1995), EN23953 (2005) and the proposed CECED measurement method (for a 1-door cabinet)

	Type	Initial door opening (s)	Other door opening time (s)	No/hr	Door opening test (h)	Total door openings	Total test (h)	Total time door open (s) per 24 hr
EN441	All	180	12	6	2 x 12	2 x 72	48	1044

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[1] European Committee of Domestic Equipment Manufacturers: http://www.ceced.eu/

	Type	Initial door opening (s)	Other door opening time (s)	No/hr	Door opening test (h)	Total door openings	Total test (h)	Total time door open (s) per 24 hr
EN23953	All	180	6	6	12	72	24	612
CECED	Upright chilled	120	6	6	12	72	24	552
CECED	Upright freezer	60	6	6	2 x 4	48	24	348
CECED	Counter chilled	120	6	6	12	72	24	552
CECED	Counter freezer	120	6	6	12	72	24	552

2.1.1. The model

A lumped steady state empirical MS Excel based model was developed to calculate energy used by professional cabinets during closed door, EN441, EN23953, and CECED tests. The model was then used to suggest a normalisation methodology to compare the energy used by the cabinets across the standard measurement methods.

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) 2-door under counter cabinet. In all cases (regardless of the standard measurement method) energy was calculated over a 24 hour period and compared to test data over the same period.

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)

3. As lighting is rare in professional cabinets it was ignored
4. Energy used by controllers was ignored as it is low

2.1.2. Model heat loads

Transmission across the cabinet insulation

The heat load through the cabinet fabric was calculated using the following equation:

$$Q = UA\Delta T \qquad \text{(Equation 1)}$$

Where:

Q = heat (W)

U = overall heat transfer coefficient ($W.m^{-2}.K^{-1}$) obtained from:

$$\frac{1}{U} = \frac{1}{h_i} + \frac{1}{h_o} + \frac{x}{k} \qquad \text{(Equation 2)}$$

Where:

h_i = heat transfer coefficient on inside of cabinet ($W.m^{-2}.K^{-1}$)
h_o = heat transfer coefficient on outside of cabinet ($W.m^{-2}.K^{-1}$)
x = thickness of insulation (m)
k = thermal conductivity of fabric ($W.m^{-1}.K^{-1}$)
A = surface area of walls (m^2)
ΔT = air temperature difference between outer and inner wall (K)

The following inputs were used in the model:

External dimensions of the cabinet refrigeration cavity

Insulation thickness (assumed to be constant on all walls) = 55 mm

k for polyurethane = 0.025 $W.m^{-1}.K^{-1}$ (obtained from Jarfelt and Rammas, 2006)

h_o = 5 $W.m^{-2}.K^{-1}$

h_i = 5 $W.m^{-2}.K^{-1}$ (from Knackstedt et al)

ΔT chilled = 27 K

ΔT frozen = 52 K

From these the following were calculated:

- Internal dimensions of the cabinet refrigeration cavity (calculated from external dimensions minus insulation depth)
- Internal volume of cabinet
- External area of cabinet (half depth of insulation used for calculation)
- U value

Fans (evaporator)

Fan heat load was assumed to be equal to the fan power (i.e. all heat from fan added to cabinet).

The value for fan power was based on fitted values from RD&T data on 690 L cabinets and scaled with cabinet internal volume. It was assumed that evaporator fans operated all the time.

Defrosts (freezers only)

Chillers were assumed to defrost through passive (or off-cycle) defrosts.

Defrosts in freezers were assumed to occur 4 times per day. The defrosts were assumed to be electric and that 80% of the defrost energy was added to the cabinet (i.e. the defrost was only 20% efficient in melting the ice). This is a reasonable assumption based on work from Bansal et al (2010) and Evans and Lawrence (2008).

It was assumed that all ice on the evaporator was melted in defrosts and that defrosts all operated for 27 minutes, 4 times per day. The impact of condensation of any ice melted and converted to steam or the re freezing of any water remaining in the cabinet after the defrosts were ignored. Defrost heaters were scaled with cabinet internal volume.

Cabinet gasket

Heat load across the cabinet gasket was calculated using the same equations as for transmission. The following inputs were used in the model:

- External width x height of cabinet (assumed that gasket around door filled whole of front face of cabinet)
- Gasket thickness (assumed to be constant on all faces) = 15 mm
- k for rubber = 0.29 W.m^{-1}.K^{-1} (obtained from http://www.electronics-cooling.com/2001/11/the-thermal-conductivity-of-rubbers-elastomers/)
- Heat transfer coefficient and temperature differences identical to those used for transmission across walls

Door openings

The impact of door openings was calculated for:

- The heat gain to test packs during the initial door opening period at the start of the test
- The heat gain to the air during the shorter door openings throughout the test

Heat gain to test packs during the initial door opening period

During the initial door opening period the temperature of test packs increases. Once this heat has been removed the test packs generally remain relatively stable in temperature (although it should be noted that this varies considerably between cabinets – depending on whether cabinets have the capacity to remove added heat). The assumption was made that the heat added to the test packs during the initial door opening period was equal to the energy required by the refrigeration system to remove this heat. The effect of heat added to the cabinet internal surfaces and shelves was ignored.

Analysis of RD&T test data found that during the initial 3 minute door opening period of an EN441 test the temperature of chilled packs rose by between 0.1 to 0.7°C (mean 0.4°C) and the temperature of frozen packs rose between 1.9 and 2.1°C (mean 2.0°C). The assumption was made that the temperature increase of test packs during the initial door opening could be scaled linearly with initial door opening period (this is a reasonable assumption as the heat gain is all sensible heat and the temperature difference between ambient external temperature and internal cabinet temperature when the door is opened is unlikely to change dramatically between the different door opening times of interest, i.e. between 1 and 3 minutes). An assumption was also made that the temperature of all test packs rose by the same level. In reality this is not correct as pack temperatures will rise by different amounts depending on their location in the cabinet. In addition the RD&T data used to assess pack temperature rise was all based on centre temperature of 500 g 'm' (tylose measurement) packs. In reality the surface of any pack will be considerably higher in temperature during a door opening than the centre. Therefore the mean values used to assess heat gain to packs may underestimate heat gains. We could not find better data in the timeframe of this study but a sensitivity analysis showed that a change in this temperature has a significant impact. We suggest this issue could be explored further if additional work is carried out on normalisation.

Heat load from the test packs was calculated using the following equation:

For sensible heat:

$$Q = mc\Delta T \qquad \text{(Equation 3)}$$

Where:

m = mass of test packs (kg)
c = specific heat capacity ($kJ.kg^{-1}.K^{-1}$)
ΔT = temperature difference of test packs before and after door openings (K)

The following inputs were used in the model:

c for tylose = 3.7 $kJ.kg^{-1}.K^{-1}$ for chilled and 2.0 $kJ.kg^{-1}.K^{-1}$ for frozen test packs (obtained from EN23953, 2005)
ΔT chilled = 0.4 K (based on mean values from RD&T test data)
ΔT frozen = 2.0 K (based on mean values from RD&T test data)
m = based on mass of test packs and scaled with cabinet internal volume[2]

Heat gain to the air during the shorter door openings throughout the test

Heat gain during the short but regular 12 or 6 second door openings were assessed as a function of the volume of ambient air replacing the cold air in the cabinet during each opening. As in both chilled and frozen cabinets the air is cold and denser than the ambient air outside of the cabinet, the cold air will fall from the cabinet and be replaced by warm ambient air. The ambient air has both a sensible and a latent heat load on the cabinet and these were calculated using the following equations:

Heat load to the air was calculated using the following equations:

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[2] Loading of test packs is similar in all the test standards examined and is based on loading requirements in EN23953: 2005.

For sensible heat:

$Q = mc\Delta T$ (Equation 4)

For latent heat:

$Q = mL$ (Equation 5)

Where:

Q = heat extracted (kJ)
m = mass of air (kg)
c = specific heat capacity of air (kJ.kg^{-1}.K^{-1})
ΔT = temperature difference between cabinet and room (K)
L = latent heat of water (kJ.kg^{-1})

The following inputs were used in the model:

Specific heat capacity of air at atmospheric pressure = 1.005 kJ.kg^{-1}.K^{-1}
Density of air 3°C[3] = 1.28 kg.m^{-3}
Density of air -22°C[4]= 1.41 kg.m^{-3}
ΔT chilled = 27 K
ΔT frozen = 52 K
Latent heat of water-condensation = 2260 kJ.kg^{-1}
Latent heat of water-fusion = 334 kJ.kg^{-1}
Water content of air at climate class 4 = 0.0154 kg.kg^{-1}
Water content of air at 3°C[3] = 0.005 kg.kg^{-1}
Water content of air at -22°C[4] = 0.001 kg.kg^{-1}

An assumption was made that the whole volume of air inside the cabinet (the internal volume minus the volume of the test packs) was potentially lost from the cabinet. The amount of cold air that was lost from the cabinet was calculated using information from Knackstedt et al (1995). Knackstedt et al showed that in the initial 2 seconds of a door opening that the air flow was stagnant. It then took 6-8 seconds for a definitive flow pattern to establish. The actual flow pattern varied between several configurations and this was influenced by the number of shelves and cabinet loading. The most common flow pattern established in 30-50% of cases resulted in air dropping from the top and bottom shelves but air from the middle shelves being re-circulated (although there was some entrainment due to flow from the upper shelves). In the door opening periods within the standard measurement methods the cabinet door is opened for either 12 or 6 seconds. This means that in the shorter door opening period that full flow is not established but that in the longer 12 seconds door openings a full flow pattern has just begun to be established.

In the model the stagnant 2 second period at the start of each door opening was removed from each door opening period (i.e. the 6 second door opening was adjusted to 4 seconds and the 12 second door

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[3] Assumed to be cabinet air temperature for chiller
[4] Assumed to be cabinet air temperature for freezer

opening adjusted to 10 seconds). It was assumed that all the cold air from the cabinet would then be replaced by ambient air over a 6 second period and that the replacement was linear with door opening period. Therefore in the adjusted 10 second door opening for upright cabinets it was assumed that 1.67 'volumes' of air was lost from the cabinet (the assumption was made that the air from ambient was chilled by the cabinet structure and test packs and so greater than 1 volume of air could be lost if over a relatively short period of time).

The effect of conduction and radiation during all door openings was ignored as this is a relatively small part of the overall heat load during door openings (less than 5% according to Knackstedt et al, 1995).

2.1.3. Efficiency of heat extraction

The electrical energy used to extract the added heat was calculated using a refrigeration COP (coefficient of performance).

2.1.4. Auxiliary heat loads

Fans

Power consumed by evaporator fans was added as an auxiliary energy consumption.

Condenser fans do not operate continually (they generally operate at the same time as the refrigeration system). Typical operation times for chillers and freezers were extracted from RD&T data. All fan power was scaled with cabinet internal volume.

Defrosts (freezers only)

Chillers were assumed to defrost through passive (or off-cycle) defrosts.

Defrosts in freezers were assumed to occur 4 times per day. The defrosts were assumed to be electric. Defrosts all operated for 27 minutes, 4 times per day. Defrost heaters were scaled with cabinet internal volume.

Temperature setting

It should be noted that when normalising test data between the different test standards that the model does not take into account that the cabinet set point may be able to be adjusted to achieve the same maximum temperatures in each test. This is particularly the case between EN441 and the other test standards as the additional length of door openings in EN441 provide a higher heat load which some cabinets cannot extract. This means that the cabinet set point needs to set at a lower level to achieve a lower temperature at the start of the test to provide a 'buffer' for the cabinet to be able to maintain temperatures of the loading packs below the required level. The model does not take this into account as there is large variability between cabinets and without a more complex model it is almost impossible to calculate.

3. Fitting the model

3.1. Available data for model fitting

To fit the model limited data were available. The following data were used:

1. RD&T test data on closed door versus EN441 (door opening) tests
2. Data from the Danish Technological Institute (DTI)[5]:
    - comparison of energy used in one chiller when tested to EN441, EN23953 and an adapted EN23953 test with 10 second instead of 6 second door openings
    - comparison of energy used in one freezer when tested to EN441 and EN23953

    In both cases full test reports were provided so that data could be checked and assessed to ensure that the data provided a direct comparison between data sets (e.g. temperatures in the cabinet were almost identical etc).
3. A methodology from CECED to translate between EN441 and the proposed CECED standard. It should be stressed than no background calculation methodology or data were supplied and so there was no method to validate the information provided.
4. Data from the UK ECA[6] scheme was compared to the predicted model results to provide further validation.
5. Where available published literature was compared to measured and model data.

The model was fitted to the data by adjusting the following within reasonable ranges:

- Cabinet COP
- Defrost energy
- Condenser run time
- Air exchange factor
- Evaporator and condenser fan power

The following values were used:

COP for the freezer:	0.8
COP for the chiller:	1.5
Defrost heater power:	380 W per m^3 of internal volume for upright cabinets and under counter cabinets
The air exchange factor:	90% for upright cabinets and under counter cabinets
Evaporator fan power for uprights:	30 W per m^3 of internal volume of cabinet
Evaporator fan power for under counters:	32 W per m^3 of internal volume of cabinet
Condenser fan power for uprights:	45 W per m^3 of internal volume of cabinet
Condenser fan power for under counters	62 W per m^3 of internal volume of cabinet
Run time condenser fan chiller:	50% of time
Run time condenser fan freezer:	90% of time

Figures used were based on RD&T data based on a typical single door upright cabinet and a 2-door under counter cabinet.

A summary of the data used for fitting is provided in Tables 2 a. to 2 d. presented below.

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[5] Danish Technological Institute: http://www.teknologisk.dk/

[6] Enhanced Capital Allowance (ECA) Scheme: http://etl.decc.gov.uk/etl

Table 2 a. Data used to fit the model - Data from RD&T

Source	Cabinet characteristics		Test results			
	Cabinet type	Volume (m^3)	Consumption stable no door openings (kWh/24h)	Consumption EN441 (kWh/24h)	Difference between no door openings and EN441 (% increase)	Temp increase due to door initial opening (°C)
CHILLERS						
RD&T	*1 door vertical*	*0.7*	*0.96*	*1.84*	*91.7%*	*0.7*
RD&T	1 door vertical	0.7	1.35	2.12	57.0%	0.5
RD&T	1 door vertical	0.7	1.59	2.03	27.7%	0.7
RD&T	1 door vertical	0.7	1.68	2.06	22.6%	0.2
RD&T	1 door vertical	0.4	1.69	2.46	45.6%	0.6
RD&T	1 door vertical	0.7	1.76	2.23	26.7%	0.4
RD&T	1 door vertical	0.7	1.86	2.54	36.6%	0.4
RD&T	1 door vertical	0.7	3.59	4.56	27.0%	0.3
RD&T	1 door vertical	0.7	3.75	4.24	13.1%	0.1
RD&T	*1 door vertical*	*0.7*	*4.02*	*5.06*	*25.7%*	*0.2*
Mean[7]		0.7	**2.16**	**2.78**	**32.0%**	**0.4**
Alissi et al (1988)	1 door vertical	-	-	-	32.0%	-
RD&T	2 door under-counter	0.4	1.35	1.56	15.6%	0.2
FREEZERS						
RD&T	1 door vertical	0.7	5.33	8.20	53.8%	2.1
RD&T	1 door vertical	0.7	5.37	7.19	33.9%	2.0
RD&T	1 door vertical	0.7	8.22	10.47	27.4%	1.9
RD&T	*1 door vertical*	*0.7*	*10.65*	*13.57*	*27.4%*	*2.1*
Mean[8]			**6.31**	**8.62**	**38.4%**	**2.0**

Data in italics excluded

Colour coding differentiates cabinet types.

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[7] Excludes minimum and maximum values

[8] Excludes maximum value

Table 2 a. b. Data used to fit the model - Data from the DTI

Source	Cabinet type	Volume (m^3)	EN441 (kWh/24h)	EN23953 (kWh/24h)	EN23953 with 10 s door openings (kWh/24h)	Difference between EN441 and EN23953 (% increase)
DTI	1-door chiller	0.46	1.49	1.41	1.41	5.4%
DTI	1-door freezer	0.46	7.34	6.82		7.1%
Energy converted to equivalent of 0.66 m^3 cabinet						
DTI	1-door chiller	0.66	2.08	1.96	1.96	
DTI	1-door freezer	0.66	10.31	9.58		

Table 2 a.. Data used to fit the model - Data from CECED

Source	Cabinet type	EN441 to CECED (%)
CECED	Vertical/horizontal refrigerators	-10
CECED	Vertical/horizontal freezers	-15

Table 2 a. d. Data used to fit the model - Data from ECA

Source	Cabinet type	No.	EN441 (kWh/24h)
ECA	Single door Upright	141	4.18
ECA	Double door Upright	48	8.01
ECA	Double door Under counter	4	1.61
ECA	3-door Under counter	3	2.22

3.2. Fitting

The model fit compared against the data from Table 2 a. above is shown in Table 3 below. Due to the lack of available data that compared a range of conditions, the main validation was carried out against RD&T data, as it provided the largest data set that comprised at least 2 conditions.

When compared to the RD&T data, the mean model error for a cabinet of mean volume 0.7 m^3 was less than 1.1%. When compared to the adjusted (for volume) data supplied by the DTI, the model over predicted energy consumption for the chiller (by 0.75 kWh or 3.8%) but under predicted energy for the freezer (by 1.03 kWh or -16.4%). When compared to mean ECA data, the model under predicted (by on average across all volumes by up to 66%) energy consumption for all except the 3 door under counter cabinets. A comparison between the model predictions and data from the ECA scheme for upright and under counter cabinets is shown in Figure 1 and Figure 2. As can be seen, the model predictions closely follow the ECA data, tending on the whole to predict towards the higher efficiency ECA cabinets.

Although the model tends to predict the performance of an energy efficient cabinet, the percentage differences between standard measurement methods for similar sized cabinets would be expected to be similar. However, the variation in energy consumed between standards changes with size of cabinet and therefore it is not valid to use one percentage value to normalise all cabinets.

It should be noted that there is a large range of efficiencies of professional cabinets and that a reasonably efficient cabinet has been modelled. It would be beneficial to obtain further data from tests to enable further validation.

Table 3. Fitting of model, consumption in kWh/24h for each test from each source

	Data source (no. data sets in brackets) (kWh/24h)				
	RD&T	DTI[9]	CECED	ECA (mean)	Model
Upright – chilled single door					
Stable, no door openings EN441	2.16 (8)	x	x	x	2.15
EN441 test	2.78 (8)	2.08 (1)	x	4.18 (141)	2.70
EN23953 test, 12 s door openings	x	1.96 (1)	x	x	2.41
EN23953 test, 10 s door openings	x	1.96 (1)	x	x	x
Upright – chilled double door					
Stable, no door openings EN441	x	x	x	x	4.30
EN441 test	x	x	x	8.01 (48)	5.40
EN23953 test, 12 s door openings	x	x	x	x	4.82
EN23953 test, 10 s door openings	x	x	x	x	x
Upright – freezer single door					
Stable, no door openings EN441	6.31 (3)	x	x	x	6.32
EN441 test	8.62 (3)	10.31 (1)	x	x	8.33
EN23953 test, 12 s door openings	x	9.58 (1)	x	x	7.32
EN23953 test, 10 s door openings	x	x	x	x	x
Under counter – double door chilled					
Stable, no door openings EN441	1.35 (1)	x	x	x	1.29
EN441 test	1.56 (1)	x	x	1.61 (4)	1.58
EN23953 test, 12 s door openings	x	x	x	x	1.42
EN23953 test, 10 s door openings	x	x	x	x	x
Under counter – 3 door chilled					
Stable, no door openings EN441	x	x	x	x	1.90
EN441 test	x	x	x	2.22 (3)	2.35
EN23953 test, 12 s door openings	x	x	x	x	2.11
EN23953 test, 10 s door openings	x	x	x	x	x

The comparison between the results from the model and ECA data for upright chilled and frozen cabinets illustrated in Figure 1 below shows that the model is well aligned with ECA data and tends to predict the performance of energy efficient cabinets.

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[9] Data converted to equivalent volume

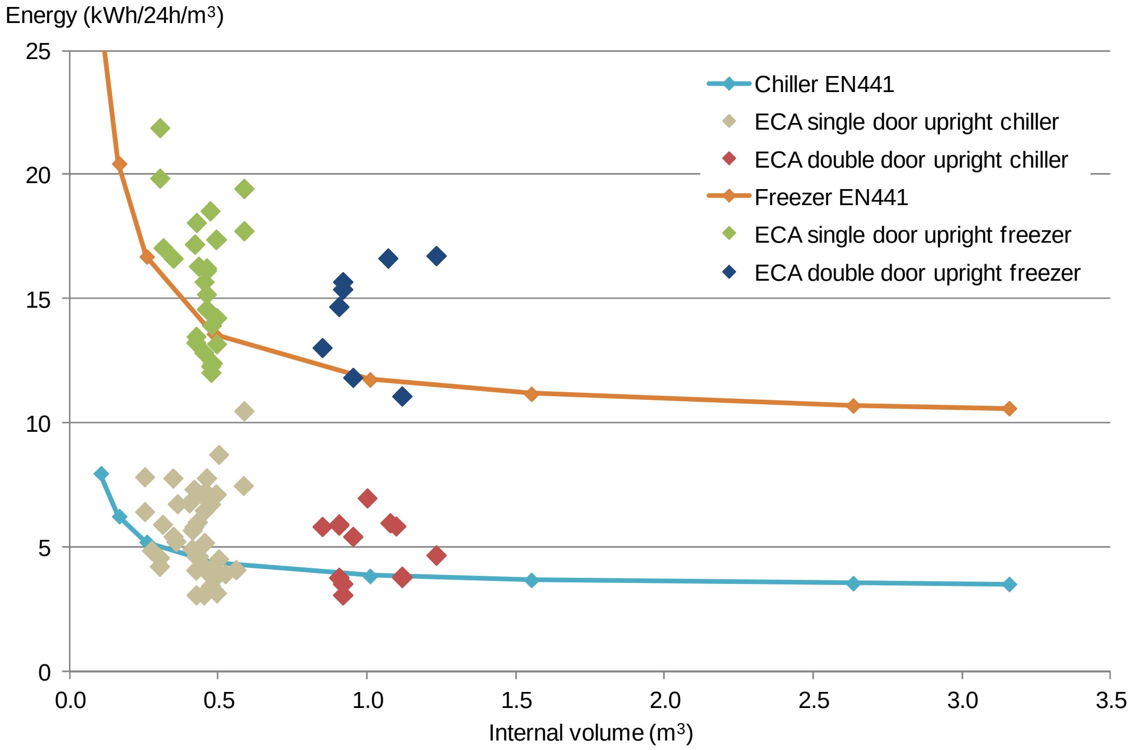

Figure 1. Comparison between model (solid lines) and ECA data for upright chilled and frozen cabinets.

Only very little data was available from the ECA for under counter chilled cabinets and no data was available for frozen cabinets. The comparison between the model and the ECA data illustrated in Figure 2 shows that the results of the model are well aligned with the available data from the ECA and seem to predict the performance of energy efficient cabinets

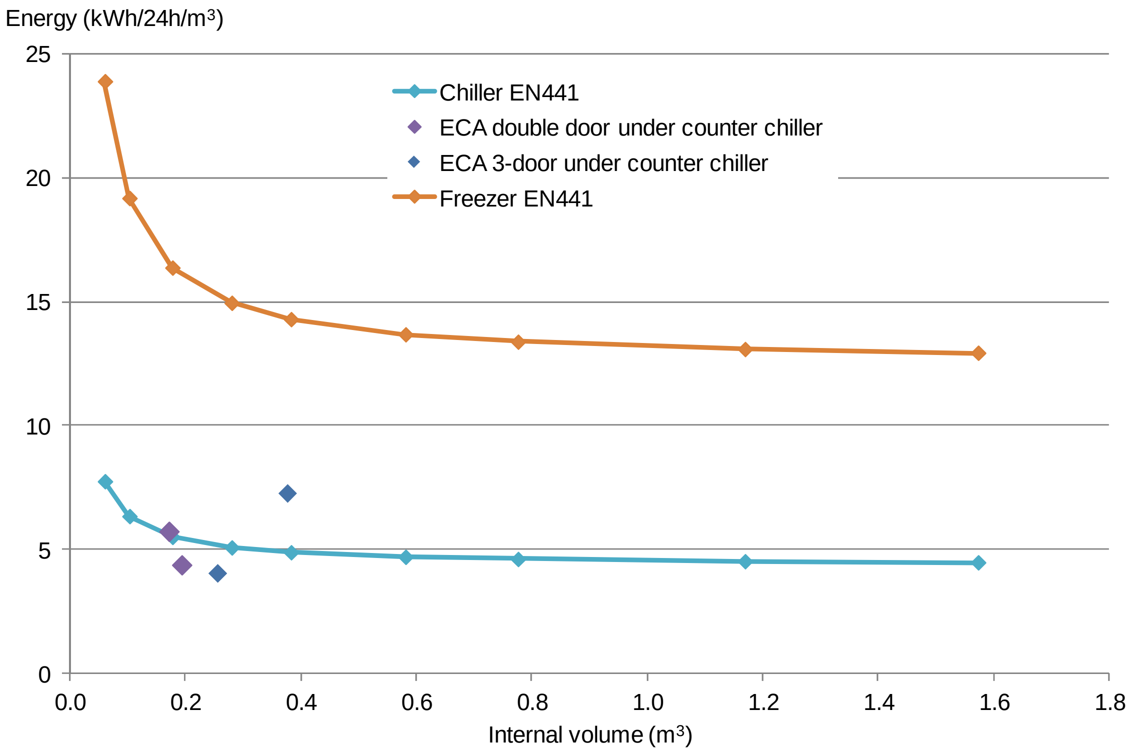

Figure 2. **Comparison between model (solid lines) and ECA data for under counter chilled and frozen cabinets.**

4. Normalisation

Using the model as fitted above, the energy used for each of the standard measurement methods can be predicted. The predicted energy consumed by upright chillers and freezers is shown in Figure 3 and the energy used by under counter units shown in Figure 4.

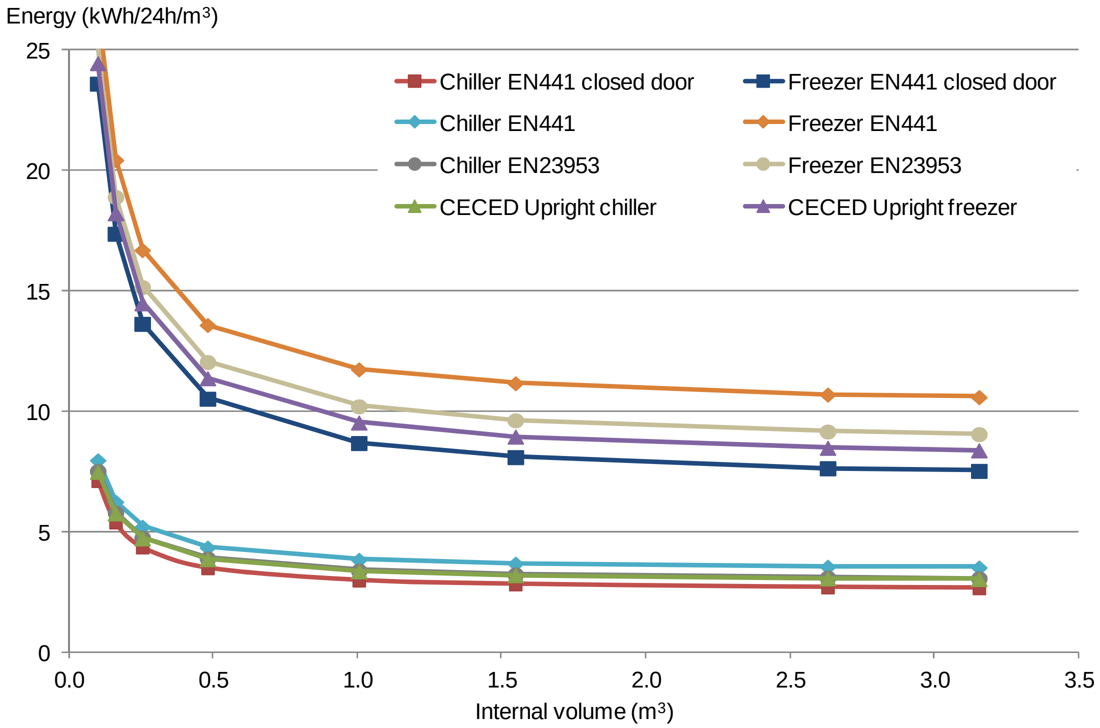

Figure 3. Energy used in various measurement methods by upright chillers and freezers.

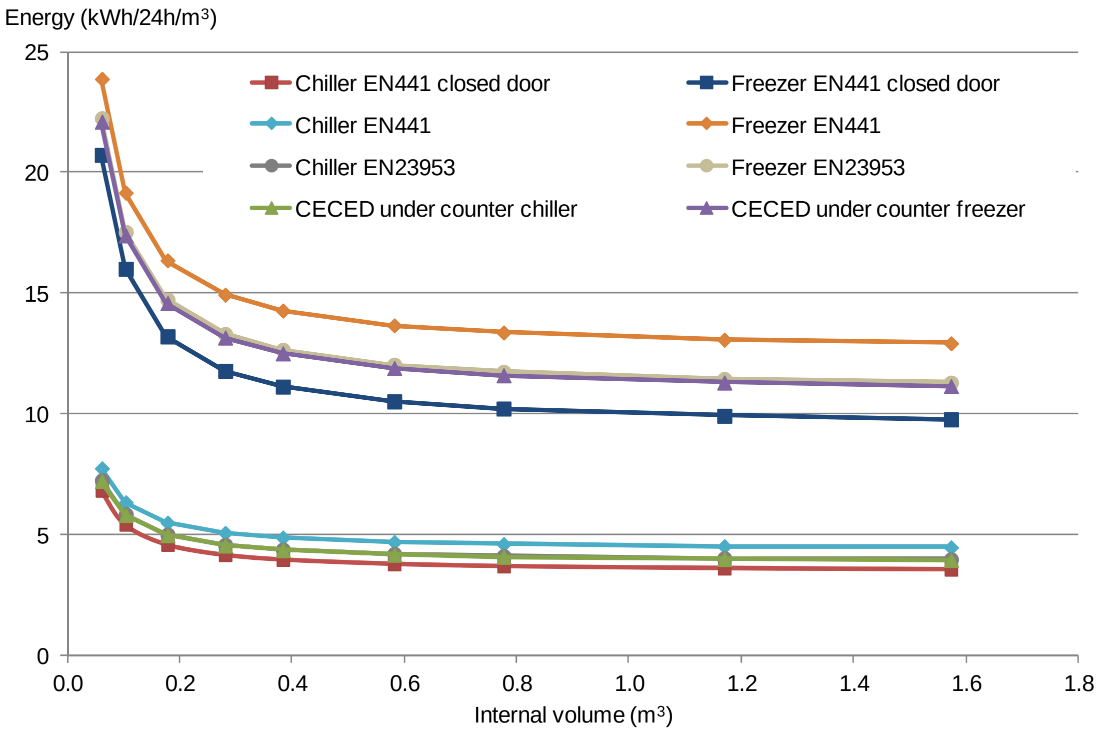

Figure 4. Energy used in various measurement methods by under counter chillers and freezers.

Results to translate between the standard measurement methods using the ‘standard’ cabinets used for the validation are shown in Table 4. The normalisation percentage change between each standard measurement method varies according to cabinet size and therefore the model itself, or alternatively Figure 5 and Figure 6 should be used to obtain the correct normalisation percentage figure for each cabinet size.

Table 4. Normalisation between measurement methods for cabinets

Standard	Cabinet type	kWh/24h chilled	kWh/24h frozen	Percentage difference chilled	Percentage difference frozen	Normalisation
UPRIGHT (658 litres gross internal volume):						
EN441-no door openings	All	2.15	6.32	n/a	n/a	n/a
EN441	All	2.70	8.33	26.0	31.8	No door openings normalised to EN441
EN23953	All	2.41	7.32	-10.9	-12.1	EN441 normalised to EN23953
CECED	Upright chiller	2.39	n/a	-11.7	n/a	EN441 normalised to CECED
CECED	Upright freezer	n/a	6.88	n/a	-17.4	EN441 normalised to CECED
UNDER COUNTER (320 litres gross internal volume):						
EN441-no door openings	All	1.29	3.63	n/a	n/a	n/a
EN441	All	1.58	4.62	22.3	27.3	No door openings normalised to EN441
EN23953	All	1.42	4.11	-9.9	-11.1	EN441 normalised to EN23953
CECED	Counter chilled	1.41	n/a	-10.5	n/a	EN441 normalised to CECED
CECED	Counter freezer	n/a	3.90	n/a	-15.5	EN441 normalised to CECED

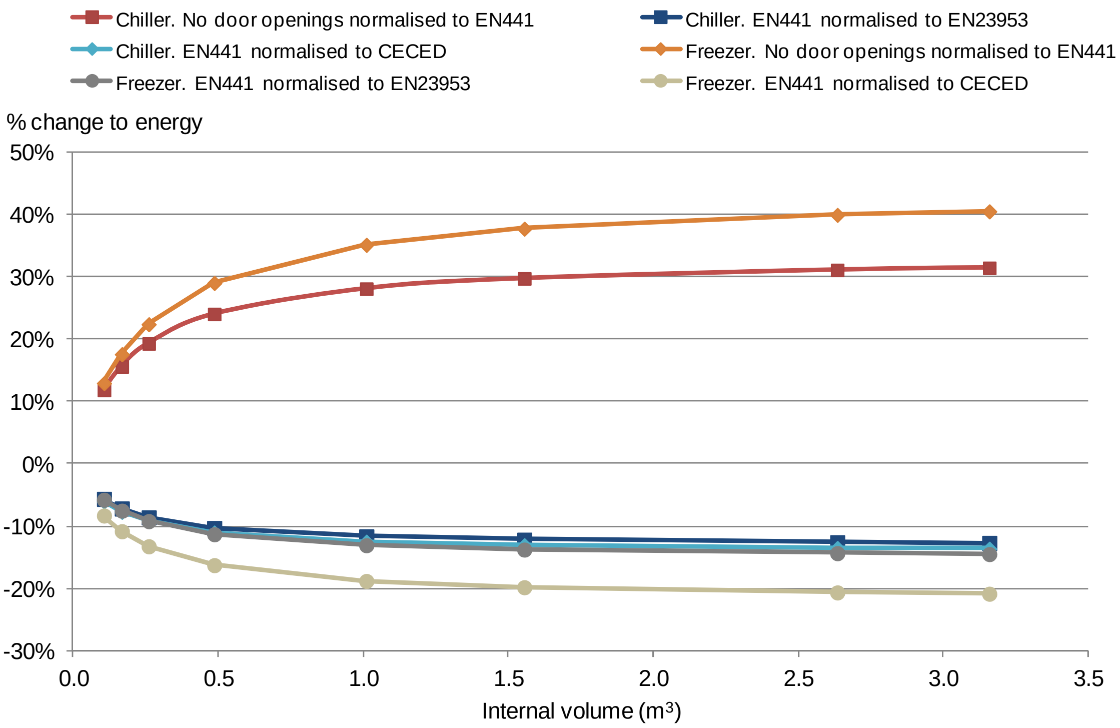

Figure 5. Normalisation conversion for upright chillers and freezers up to 3.2 m^3 internal volume

Figure 5 (above) and Figure 6 (below) show the evolution of the normalisation conversion factors in function of the evolution of the internal volume of the cabinets, both for upright and for under counter cabinets.

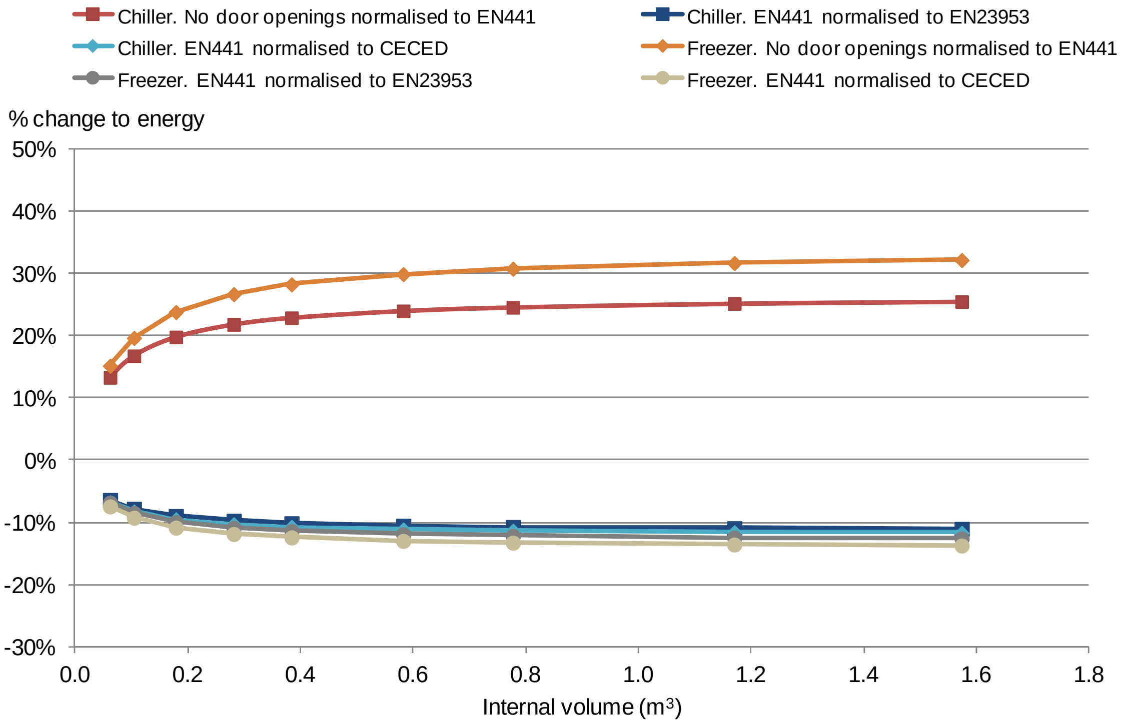

Figure 6. Normalisation conversion for under counter chillers and freezers up to 1.6 m^3 internal volume

According to the model, the normalisation conversion factors are less affected by the size of the cabinet for under counter cabinets than for upright cabinets.

Similarly, the model could also be used to define an equation for the minimum efficiency levels for service cabinets that would correspond to physical reality.

4.1. Comparison with CECED normalisation approach

The CECED recommendations for normalisation do not differentiate between upright and under counter cabinets (or different sized cabinets). Compared to the CECED recommendations the model predicts a larger normalisation reduction in energy for uprights and a lower reduction for under counters (Table 5).

Table 5. Comparison of normalisation recommended by CECED and the model predictions

	CECED	Model (assuming single upright or 2 door under counter cabinet)
Convert EN441 data to the CECED standard for all chillers	-10%	-13.8% for upright cabinets -8.5% for under counter
Convert EN441 data to the CECED standard for all freezer	-15%	-20.1% for upright cabinets -11% for under counter

5. Classification of cabinets

Information from manufacturers has indicated that some manufactures produce heavy duty cabinets and also light use cabinets. These are different from the ‘standard’ professional cabinets that are listed in the UK ECA scheme and Danish Positive list. Information provided by manufacturers had indicated that almost all light use cabinets would fail an EN441 test on temperature control and that for some manufacturers this can equate to 50% of their sales (in volume).

If the lighter usage CECED measurement methods were implemented manufactures report that the light use cabinets may pass the temperature test. However, this needs to be validated experimentally. Almost inevitably if these cabinets passed the temperature test they would also pass the energy thresholds as they would be fitted with small semi-domestic type refrigeration systems.

The heavy usage cabinets should easily pass the CECED standard temperature test but may have oversized refrigeration systems to cope with their designed high usage. The compressors on the high use cabinets would be slightly more efficient than the compressors on the light use cabinets and so this should be a benefit. High use cabinets would operate for short periods in a CECED test but this would potentially only be an issue if the cabinets operated using capillary expansion. The cabinets may require longer run times and experience ‘off-cycle’ losses (losses across the capillary during off cycles). Off-cycle losses can be prevented with a liquid line solenoid. Some manufacturers already fit liquid line solenoids to standard cabinets and so it is unlikely to be a significant issue for manufactures.

Should the Commission decide to explore this issue further, more work would be required to validate the above assumptions. Possibly the only method to truly obtain this validation, would be through testing the light and heavy usage cabinets to the CECED standard.

A possible issue is that the difference could probably only be based on “intended used”: light use cabinets tend to be built from cheaper components (cost light use cabinets would be up to half price of standard/heavy duty cabinet), may have a pre formed inner liner (similar to a domestic refrigerator) rather than a stainless steel inner, will have smaller refrigeration systems etc but there is no real technical difference

6. Representative testing

1. Information obtained from Gram indicated that 50% of their sales are under counters and 50% uprights. Twenty percent of under counters are bespoke models (i.e. 10% of total sales).
2. A significant proportion of the Foster and Williams sales are bespoke models.
3. Cabinets from the majority of southern European manufactures are claimed to be less varied. This could be confirmed through examination of product catalogues.

Testing bespoke models that often have a large number of doors or drawers presents considerable problems in a measurement method where each door/drawer needs to be opened within a 10 minute time period. For a typical bespoke cabinet with for example 10 doors/drawers this would mean for an EN441 test that each door/drawer would be opened in sequence for 3 minutes at the start of the test (i.e. a total of 30 minutes of door openings). The 3 minute door opening at the start of the test is designed to simulate cabinet loading. However, with the small drawers it is unlikely that it would require 3 minutes to load each door/drawer. Once the initial door/drawer opening period is complete each door/drawer would then be opened every 10 minutes in a sequence (i.e. one drawer would be opened every minute). This is claimed by manufacturers to be a much more challenging test than would be encountered by these products in real use. Ideally a test should be designed to simulate real use as much as possible as then the cabinets will not be over designed for real life usage.

The door/drawer openings are also claimed to be a technical challenge by manufactures as they would have to build door opening mechanisms capable of opening each door/drawer in the required sequence. Although this is not in reality particularly difficult it is unlikely that any manufacturer or test facility has such a mechanism available (If cabinets have multiple doors/drawers (some may have 10) they have to be opened in a sequence in the test standards. This means that one door/drawer out of the 10 will be opened every minute. Although this is technically possible it requires a huge and complicated door opening mechanism).

One option would be for cabinets with more than 3 doors/drawers to be tested in a sequence where one door/drawer is opened every 3.3 or 5 minutes. Ideally some usage data would be useful to ascertain the level of door openings in real usage of bespoke cabinets. This option would again require quite a complicated door opening mechanism and so there is potentially an option when doors or drawers are part of one refrigerated space (it is quite common that manufactures refrigerate one space in the cabinet carcass into which doors/drawers are placed) that only one door/drawer in that space need be opened.

If the Commission chooses to develop this approach, further data would be required on:

1. Numbers of bespoke cabinets
2. Configurations of bespoke cabinets (including whether door/drawers are refrigerated from a common space
3. Real life usage data on how these cabinets are used by end users

7. References

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