CLASP Commercial refrigeration equipment: mapping and benchmarking

by

Waide Strategic Efficiency Ltd, Saint Trofee and Cemafroid

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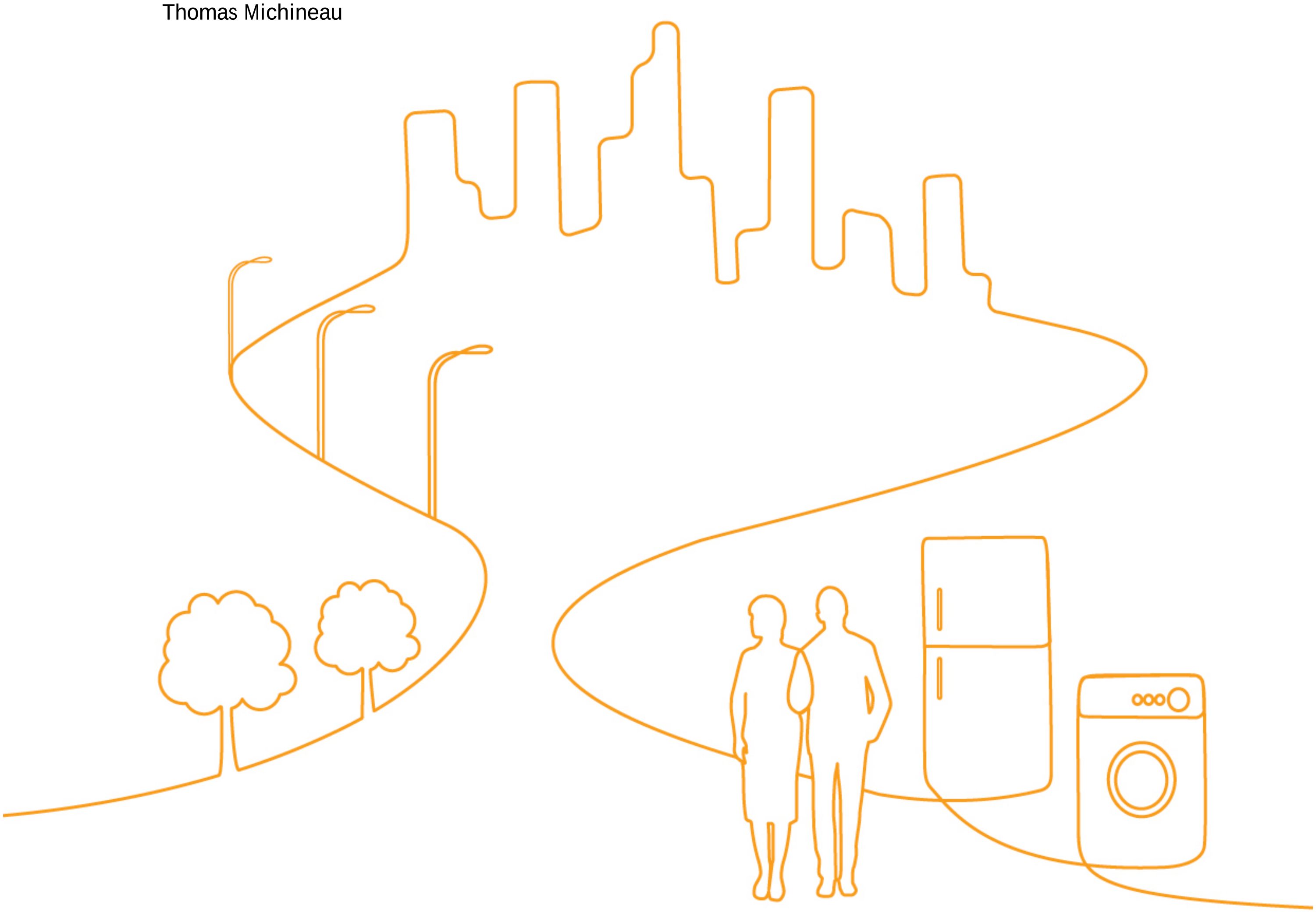

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Glossary

ASHRAE	American Society for Heating, Refrigeration and Air Conditioning Engineers
ANSI	American National Standards Institute
CEN	Commité Européen de Normalisation
Commission	European Commission
Commissioning	the process of testing, checking or calibrating the function of any building services component, to advance it to a working order
CRE	commercial refrigeration equipment
DIN	Deutsches Institut für Normung (German Standards Organization)
DOE	US Department of Energy
ECM	electronically commutated motor
EEA	European Economic Area
EU	European Union
European standard	a standard adopted by a European standardisation organisation
HER	heat extraction rate (the COP (coefficient of performance) of CRE)
HT	high temperature (see ISO EN 23953)
HVAC	heating ventilation and air conditioning
Integral	an integral (self-contained) CRE device that does not have a remote condenser, see also plug-in and self-contained
IEA	International Energy Agency
IEC	International Electrotechnical Commission
ISO	International Organization for Standardization
LCC	life-cycle cost
LLCC	least life-cycle cost
LT	low temperature (see ISO EN 23953)
MEPS	minimum energy performance standard
MS	Member State (of the European Union)
MT	medium temperature (see ISO EN 23953)
National standard	a standard adopted by a national standardisation body
PSC	permanent split capacitor
Plug-in	an integral (self-contained) CRE device that does not have a remote condenser, see also integral and self-contained
RDC	refrigerated display cabinets
Reach-in-cooler	a broad category of commercial refrigeration equipment that includes: refrigerated display cabinets, beverage coolers, and commercial service cabinets

Remote	a non-integral (not self-contained) CRE device that does have a remote condenser
RSA	Republic of South Africa
Self-contained	an integral (self-contained) CRE device that does not have a remote condenser, see also plug-in and integral
Standard	a technical specification, adopted by a recognised standardisation body, for repeated or continuous application. Compliance is not normally compulsory, unless the standard is referred to in legislation
TDA	total display area
TEC	total energy consumption
Thermostat	a device that responds to temperature in a space, pipe, etc., to switch an item on or off. The control provided is usually less precise than using sensors, controllers and actuators, but thermostats can have advantages in terms of low cost and robustness (e.g. for safety cut-outs). These are low-cost devices and generally provide poor control compared with more sophisticated controls
US(A)	United States (of America)
Variable speed	adjusts the speed of a fan, motor or pump to match its duty to the load or control load or demand. Reducing the speeds of these devices will also reduce energy use
VM	vending machine

EXECUTIVE SUMMARY

This report presents the findings of the CLASP mapping and benchmarking study on commercial refrigeration equipment (CRE) conducted by Waide Strategic Efficiency, Saint Trofee and Cemafroid. The focus of the study is centred on commercial reach-in coolers and on refrigerated vending machines. In the case of reach-in coolers it considers products such as refrigerated display cabinets and beverage coolers but does not address professional refrigerated service cabinets (i.e. the type of products which store but do not display merchandise). The scope of the study is confined to addressing the energy performance of the reach-in cooler cabinets (be they sold as integrated or remote cabinet types) and does not address the performance of the entire refrigeration system for remote cabinet types installed in situ.

The analyses in the study are conducted for nine target economies: Australia, Brazil, China, Europe, India, Japan, Mexico, South Africa (RSA) and the USA and also concern international test procedures. Specifically, for each of these economies and products the study:

- documents and analyses energy performance test procedures
- documents energy efficiency policies
- clarifies the ranges in energy efficiency of product markets
- gathers data on stocks and sales
- benchmarks product efficiency by comparing results across different test procedures
- assesses higher energy efficiency design options and potential efficiency improvement cost-benefits
- establishes the potential for energy savings at the macro scale

The data gathered are of varying quality and in some instances has had to be inferred from other sources and this constitutes a limitation in the reliability of some of the findings. In general where countries have had no history of introducing energy efficiency policy measures for these products there is less data on energy performance available in the public domain and analyses of efficiency become more speculative.

In general though the work conducted has enabled product performance to be benchmarked from one economy to another and for comparisons of energy performance to be made. Estimates of the total energy consumption of commercial refrigeration equipment have also been derived.

Reach-in coolers

Reach-in coolers such as refrigerated display cabinets and beverage coolers constitute the bulk of commercial refrigeration energy use for merchandising of refrigerated products.

Among the target economies energy efficiency policies such as standards and labelling have been introduced in Australia, China, Japan, Mexico and the USA and are currently under development in the European Union. The project team is not aware of any equivalent developments in Brazil, India or South Africa.

All of the target economies have a designated test procedure to measure the energy performance of reach-in coolers but these can have significant dissimilarities. China, the EU, Brazil, Japan and South Africa use test procedures which are aligned with the international ISO test procedure. Australia uses a test procedure that is largely aligned with an older version of the ISO test procedure, while India, Mexico and the USA all use test procedures that are unique to themselves. Analysis of these test procedures within this study has allowed theoretical conversion formulae to be developed for the US, Mexican and ISO test procedures and thus permits conversions to be made between most of the reach-in cooler energy performance data sets which were identified in the study. This has allowed a simplified benchmarking to be undertaken and comparisons to be made in the performance by reach-in cooler type across some of the major markets. The conversion formulae, while partially informed by comparative testing in some instances, are not corroborated by comprehensive corroborative testing and thus their accuracy is unknown. They are thus only suitable for gaining approximate insights into the relative performance of products sold on different markets, which is how they are applied in the study.

Specifically the work done entailed:

- identification of all the national test procedures applied in the target economies and their equivalence to other commonly used international or national test procedures
- examination of similarity and differences in how the efficiency metrics are derived and applied in the different economies
- comparison of the test procedures and identification of potential issues that are likely to affect the comparability of nominal test results
- comparison of the differences in the testing procedures and protocols and assessment of the expected impact on rated energy performance associated with variations in: testing conditions, testing methods, efficiency calculation methods, uncertainty of measurements, tolerances, etc.
- derivation of quantified conversion formulae to show how the energy consumption of some of the principal refrigerated display cabinet types would be expected to vary as a function of the test procedure used for the main groupings of test procedures (ISO/EU, ANSI, Australia and Mexico). Test procedures used in all other economies are almost all found to be equivalent (or nearly so) to one of the above
- development of energy performance benchmarks from application of the conversion formulae

From this it is seen that the diverse test procedures can produce very different energy performance test results for the same equipment types. Furthermore, it is also apparent that there can be significant differences in the average energy efficiency of reach-in cooler markets, even among OECD economies, depending on the specific product type concerned, which indicates there is substantial potential for further energy savings from the broader adoption of design technologies that are already deployed in major markets.

In addition the study entailed an investigation of the following aspects:

- identification of the main energy efficiency design options for reach-in coolers and their expected incremental costs and energy savings
- gathering data, varying from the comprehensive to the inferred/anecdotal, on refrigerated display cabinet efficiency levels in the target economies (note efficiency data are missing for India due to the absence of any policy requirements but is present to varying degrees for all other economies)
- development and application of a reach-in coolers energy consumption stock model that is used to project energy impacts associated with varying efficiency scenarios

Principal findings

The detailed benchmarking exercise conducted in the study used a mix of empirical measurement and analysis of physical principles to derive conversion factors for energy measurements made under the principal test procedures for different reach in cooler types. Table ES1 shows how the rated energy consumption results would be expected to vary on average for various reach in cooler cabinet types tested under the US ASHRAE72-ANSI/AHRI 1200 test procedure and the European and wider international EN ISO 23953 test procedure

Table ES1. Estimated relative total energy consumption (TEC) for refrigerated display cabinets (as defined by EN ISO 23953), when tested according to the ASHRAE 72 – ANSI/AHRI 1200 and to the EN ISO 23953 standards*.

Cabinet type	EN ISO Classification	Compressor Location	Total energy consumption	
			ASHRAE 72 – ANSI/AHRI 1200	EN ISO 23953
MT open multi-deck	3M2	Integral	100%	95%
		Remote	100%	150–165%
LT open island	3L3	Integral	100%	106%
		Remote	100%	144%
	3L2	Remote	100%	155%
	3L1	Remote	100 %	166 %
MT bottle cooler	3M2	Integral	100%	94%

Abbreviations: LT = low temperature; MT = medium temperature

*Note, the TEC values measured under the ASHRAE 72 – ANSI/AHRI 1200 values are the reference values and set at 100%.

Some examples of the benchmarking of average energy consumption values for two types of refrigerated display cabinet are shown in Tables ES2 and ES3. These show average energy consumption results converted to US test conditions using analytical formulae derived in the study and then compare the results to the average of a 2013 California dataset. They show that the California products are less efficient than the European and Australian products for the low and medium temperature remote condenser multi-deck refrigerated display cabinets but more efficient for the integral (plug-in) cabinets. These results differ from an earlier IEA 4E benchmarking analysis principally because the analysis compares the results to a more current efficiency metric (energy use per unit retail display area) and because the methodology applied in this study takes proper account of the impact of differences in the test procedures on refrigeration system COP for remote condenser retail display cabinets.

Table ES2. Average total energy consumption/total display area (TEC/TDA) for European (RVC2, 3M2) and American remote medium-temperature multi-deck cabinets when converted to be on a comparable basis[a].

Dataset	No. of models	TEC/TDA (kWh/day.m^2)		Comparison of adjusted values to California average
		Average	Adjusted	
California database (2013)	140	7.38	7.38	100%
Eurovent database (March 2013)	237	7.46	4.74	64%
Australia MEPS registration database. RS2 unlit	209	10.30	6.51	88%
Australia energy rating database 2013	22	8.22	5.22	71%
Japan (Fukushima catalogue) 2013	45	6.36	4.04	55%
China (energy label database) 2013	7	10.76	6.83	93%
South Africa internet data 2013	48	9.88	6.27	85%

[a] Corrections applied according to the results of and approach used in Table/ES1

Table ES3. Average total energy consumption/total display area (TEC/TDA) for European and American integral medium-temperature multi-deck cabinets (3M2).

Data set	No. of models	TEC/TDA ($kWh/day.m^2$) Average	TEC/TDA ($kWh/day.m^2$) Adjusted	Comparison of adjusted values to California average
California database 2013	10	9.03	9.03	100%
Phoenix retail data (UK, 2010)	16	16.89	17.78	197%
Eurovent average TEC/TDA	Unknown	15.10	15.90	176%
Australia MEPS register. IVC2 M2	± 100	15.67	16.49	183%
Australia energy rating 2013	18	15.89	16.73	185%

[a] Corrections applied according to the results of and approach used in Table/ES1

The analysis of the techno-economic potential to improve the energy efficiency of reach-in coolers found that average potential efficiency gains from moving from the current market average efficiency levels (base case) to the efficiency levels that minimise the life cycle costs over the product life time (least life cycle cost) vary between 13% and 40% depending on the type of reach-in cooler (Table ES4). The average potential efficiency gains from moving from the current market average efficiency levels to the current maximum technically achievable efficiency levels vary between 17% and 54% depending on the type of reach-in cooler.

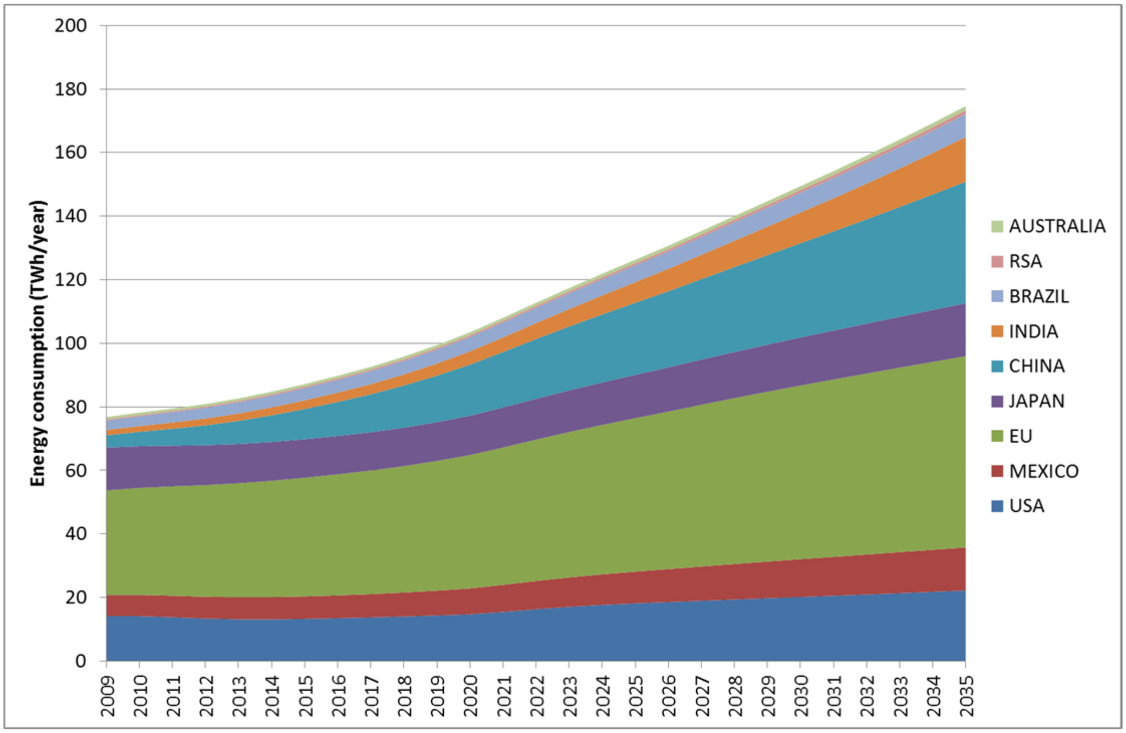
Table ES4. Techno economic energy savings potentials for reach-in coolers averaged across the nine target economies.

Reach-in Cooler type (ISO/ASHRAE)~~1~~	Average energy savings potential from base case to LLCC	Average energy savings potential from base case to maximum technically achievable efficiency
RVC2 = VOP.RC.M	13%	30%
RVC2 = VCT.RC.M	16%	29%
RHF4 = HZO.RC.L	17%	17%
IVC2 = VOP.SC.M	31%	54%
IHF4 = HZO.SC.L	24%	25%
Ice-cream lid chest freezer = HCT.SC.I	38%	45%
Ice-cream lid chest freezer = VCT.SC.I	40%	42%

[1] See Table 2 in the main body of the text for the ISO23953-2:2005 definitions for refrigerated display cabinet families and see Tables 12 and 13 for the ASHRAE definitions of display cabinet families

The actual savings potentials vary across the economies with Japan having the most efficient reach-in cooler stock on average, albeit still having potential to save more energy cost-effectively in some product classes. The total energy consumption of reach-in coolers in the nine target economies is projected to increase from 83TWh in 2013 to 175TWh by 2035 under a business as usual scenario (Figure ES1). Growth is led by the transition economies of Brazil, China, India, Mexico and RSA but current consumption is still dominated by the OECD economies, which indicates that the commercial cold chain is still comparatively underdeveloped in key transition economies.

ES 1. Estimated energy consumption for reach-in coolers in the nine SEAD economies under the Business as Usual scenario.



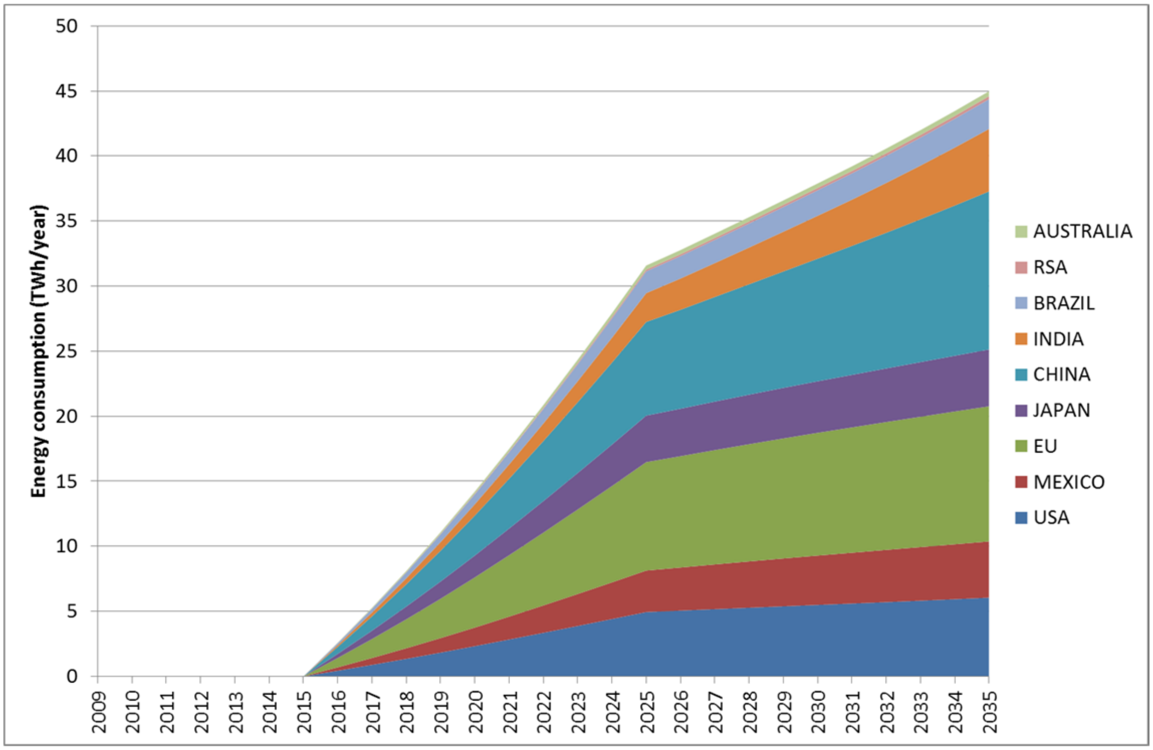
The cost effective energy savings potential (from the end-user perspective) is estimated to be 45 TWh in 2035 (26% of business as usual consumption) (Figure ES2), while the maximum technical savings potential is projected to be 56 TWh (32%) for the nine economies.

Overall this analysis shows the strong potential to deliver greater savings through more proactive policy measures. The current mix of policies is rather patchy with many economies not having energy labelling or MEPS for any reach-in cooler types.

Clearly countries that have no standards or labelling policy measures for retail display cabinets such as Brazil, the EU, India and Japan have a strong potential to save energy by introducing such measures, and the EU is in the process of doing so. Countries like China and Mexico which have measures for some equipment types (remote and integral) units respectively would benefit from developing them for all retail display cabinet categories. Interestingly, the markets with standards and labelling in place are not obviously leading the field in retail display cabinet energy efficiency. South Africa, nominally has efficiency requirements in place for some reach-in cooler types but they do not seem to be up to date nor mandatory. The US DOE rulemaking process precluded consideration of some high efficiency design options such as night covers and doors that are routinely used in some other markets and could be obliged through regulation. The Australian market does not appear to be any more efficient than the European market, which is not yet regulated. This suggests there is more to be done in all economies to increase the energy efficiency of their reach-in cooler markets.

The analysis of test procedures has also identified that there are some systematic deficiencies and notably a propensity to apply higher ambient test temperatures than would be found on average in situ. This not only arbitrarily increases nominal energy consumption but tends to skew the nominal energy savings benefits towards refrigeration circuit improvements and away from improvements in direct energy consumption such as lighting, etc.

ES 2. Estimated savings in electricity consumption for reach-in coolers in the nine SEAD economies under the Least Life Cycle Cost Scenario compared to the Business as Usual scenario.



Vending machines

The analysis for refrigerated vending machines follows a similar approach but in general there is less energy efficiency policy activity and hence fewer countries have adopted test procedures and have data on energy performance.

Interestingly there is no international test procedure for refrigerated vending machines although the topic is believed to be under consideration in ISO TC 86. The only existent test procedures are those used in the USA (ANSI), Japan (JIS), Australia and a voluntary European test procedure developed by the European Vending Association (EVA-EMP). CEN TC44 is currently developing a European test procedure for vending machines, which is drawing upon the voluntary EVA test procedure. In the absence of any formal international test procedure no test procedures have been adopted in Brazil, China, India, Mexico or South Africa.

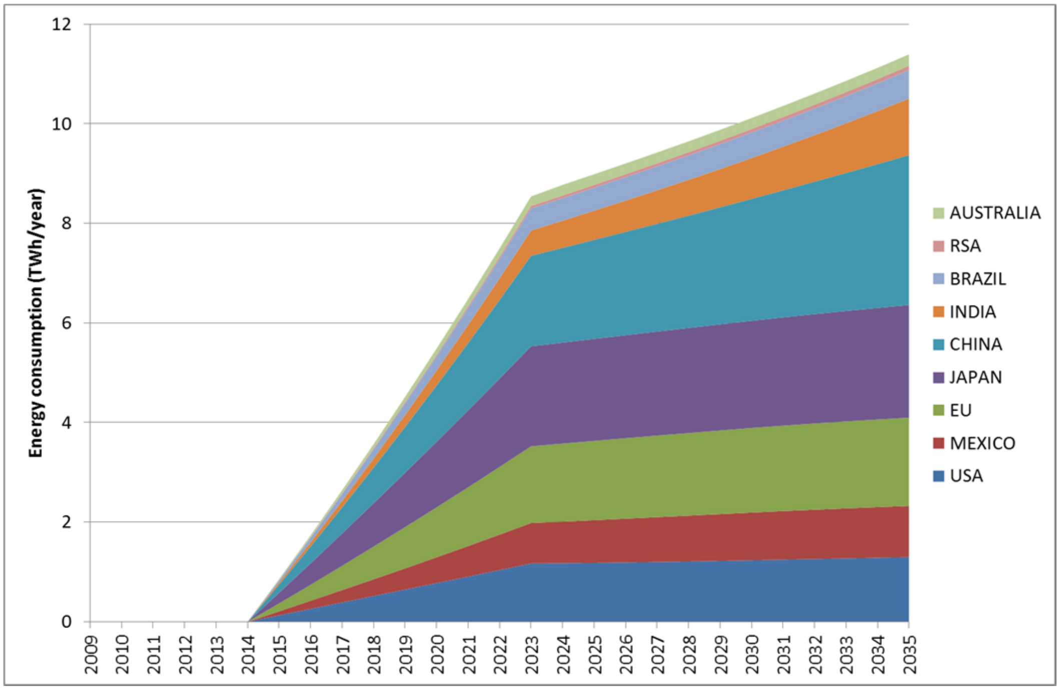
An analysis of the existing test performance rating systems used in the USA and Europe (the voluntary EVA-EMP scheme) shows that they only consider energy consumption in the idle mode and fail to reward the inclusion of presence detection or timing devices that power down the vending machine in periods of low demand. As a result they do not capture the benefits of the most promising energy saving feature. It will be important for any new pending test procedures (e.g. in Europe and ISO but also in all economies that currently do not have a test procedure) to rectify this by introducing a duty-cycle approach to measurement and rating vending machine energy performance. Future revisions of the US test procedure for MEPS should also consider making this change.

There are also significant doubts about how best to design an energy-efficiency metric for vending machines that will capture the real benefits from machines in situ and their broader place in the food/beverage cold chain. Vending machine types used around the world vary in their prevalence and function. In the USA and Australia there is a relatively high proportion of closed (opaque) drinks vending machines whereas in Europe the most common type are multi-function transparent vending machines that can serve a variety of drinks, food or snacks. Japan is comfortably the largest single vending machine market, however, and it has a variety of types depending on the service function. The type of machine has an intrinsic impact on its energy consumption as transparent multi-purpose machines, which are common in the EU, tend to require more energy to provide their service as the entire interior contents are on display and cooled simultaneously, whereas with opaque machines it is only necessary to cool products that are likely to be served imminently and the remaining drinks can be kept at ambient temperature. Furthermore, the frequency of stocking will have a significant impact on the energy used in the entire cold chain to provide the chilled drinks/food service. As a result the efficiency metric of energy used per 300 cans stored that was used in the IEA 4E mapping and benchmarking exercise will fail to capture both the difference in service and the overall impact of the service on the energy used in the cold chain. More work therefore needs to be done to devise an appropriate energy efficiency metric for vending machines that properly delineates service and the broader cold chain energy use impacts.

As a result of these constraints the techno-economic analysis of vending machine energy use only considered the most basic configurations (Class A – fully cooled, and Class B – zone cooled), which capture the most important differences in service provision. The analysis considered the energy performance under standard test conditions but then adjusted these to the energy consumption that would be more likely in actual use (this is because the ambient temperature conditions assumed in the ANSI or EVA-EMP test procedures are significantly higher than would be expected for year round average for installed vending machines, whether indoor or outdoor). The results show that there is a cost effective savings potential of about 41% on average compared to the current average refrigerated vending machine used in the nine economies. The maximum technical savings potential is around 67% compared to the average machine.

To understand the macro-scale impacts of these potential savings a refrigerated vending machine energy consumption stock model was developed. The total energy consumption of reach-in coolers in the nine target economies is projected to increase from 16.7TWh in 2013 to 27.4TWh by 2035 under a business as usual scenario. The total energy savings potential if all new vending machines sold from 2015 onwards were to be at the least life cycle cost energy efficiency level is estimated to be 11.4 TWh (41%) by 2035 across the nine economies (Figure ES3) i.e. about a quarter of the equivalent potential for reach-in coolers. Clearly there would also be a benefit from the introduction of efficiency standards and labelling for these products especially if based on more realistic test procedures that reward energy management options as well as static efficiency design option improvements. It is therefore recommended that countries should seek to add this product type into their equipment standards and labelling policy portfolios.

ES 3. Estimated savings in electricity consumption for refrigerated vending machines in the nine SEAD economies under the Least Life Cycle Cost Scenario compared to the Business as Usual scenario.



1. Introduction and scope

This report presents the findings of a mapping and benchmarking study on commercial refrigeration equipment (CRE) conducted for CLASP by Waide Strategic Efficiency, Saint Trofee and Cemafroid.

1.1 Project scope

The project scope is outlined below.

Reach-in-cooler mapping and benchmarking

a) Complete information (on the scoping study)

Gather and collate all the missing data[1] concerning the existing MEPS and labels applying to reach-in-coolers for China, India, Mexico, South Africa and the EU differentiated for each type of reach-in-cooler technology.

In order to facilitate the comparability of these efficiency policy settings (benchmarking):

- identify the national test procedures applied in the target economies and their equivalence to other commonly used international or national test procedures
- examine similarity and differences in how the efficiency metrics are derived and applied in the different economies
- conduct an initial comparison of the test procedures, and identification of potential issues that are likely to affect the comparability of nominal test results
- compare the differences in the testing procedures and protocols to assess the expected impact on rated energy performance associated with variations in: testing conditions, testing methods, calculation methods for efficiencies, uncertainty of measurements, tolerances, etc.

b) Analyse efficiency of stock and sales

- for Australia, Brazil, China, EU, India, Japan, South Africa, and the US
- including determination of average, maximum and minimum efficiency on market and in stock in each economy

Gather data on sales by reach-in-cooler product group type and by technical characteristics (including efficiency where this is known) for the key target markets of: Australia, Brazil, China, EU, India, Japan, South Africa, and the USA and analyse it to produce time-series of sales, stocks and efficiency.

c) Analyse cost-benefit data, policy implications and potential national impacts from efficiency improvements

The data gathered on the efficiency of the commercial refrigeration equipment and the cost of the equipment as a function of efficiency will be analysed to derive cost-efficiency curves for each of the target markets and CRE technologies. The markets to be addressed include:

- Australia
- Brazil
- China
- EU

[1] To complement the information that had already been gathered for: Australia, Brazil, Canada, Japan, USA in the previous scoping study

- India
- Japan
- South Africa
- USA

The reach-in-cooler product groups to be addressed include:

- The various type of refrigerated display cabinets (RDCs)

And will draw appropriate distinctions for plug-in and remote condenser types, the various common lay-out configurations, fresh or frozen food types, etc.

Note, a priori no distinction is made between product groups that provide the same cooling service and utility but have differing efficiencies (e.g. the use of clear doors or air curtains to save energy versus not using these) as these are efficiency design options that can be applied within a broader functional product category; however, the impact of such options is assessed in the technological design assessment used to determine cost-efficiency curves.

The resulting cost-efficiency curves will then be complemented by usage, lifespan and tariff data to derive life cycle cost curves as a function of energy efficiency for each market and commercial refrigeration equipment technology type.

This information will subsequently be fed into a national impact assessment model for each commercial refrigeration equipment product group. A dedicated bottom-up commercial refrigeration equipment stock model to forecast energy, economic and carbon impacts will be developed and adapted for each economy and CRE technology group using inputs gathered earlier on sales, costs-efficiency curves, tariffs, lifespans and usage profiles. This will be loaded with the input data and applied to analyse a set of commercial refrigeration equipment efficiency scenarios for each economy:

- Base case scenario (no new policy)
- Least-life-cycle cost scenario

The analysis of these scenarios will inform the impact assessment which will consider the implications of attaining any of the given efficiency levels on energy consumption.

Cold vending machines mapping and benchmarking

a) Update the existing IEA-4E analysis by analysing national sales and stock data in each economy (see b).

b) Widen scope to include China, India, and any other countries relevant to this product category

c) Provide indicative assessment of variations in annual energy demand for machines of same capacity

d) Provide indicative assessment of variations in machine efficiency and annual consumption related to policies

e) Analyse if and how cold food / snack machines differ from other cold vending machines

f) Analyse efficiency of stock and sales for Australia, Brazil, China, EU, India, Japan, South Africa, and the USA, including determination of average, maximum and minimum efficiency on market and in stock in each economy

g) Analyse cost-benefit data, technical and policy implications, and potential national impacts of efficiency improvements

The conduct of this work will follow the same approach as that described in Task c (for *Reach-in-cooler mapping and benchmarking*) but applied to vending machines rather than reach-in-coolers.

2. Reach-in coolers

A commercial refrigerated cabinet is a refrigerated appliance intended for the storage and display for merchandising, of chilled and/or frozen products at specified temperatures below the ambient temperature and which are accessible directly through open sides or via one or more doors and/or drawers.

Commercial refrigerated display cabinets may take many forms and combinations as follows:

- 'self-contained (or plug-in) appliance' refers to a factory made assembly of refrigerating components designed to compress, liquefy, expand and evaporate a specific refrigerant that are an integral part of the refrigerated equipment and consists of a storage space, one or more refrigerant compressors, refrigerant evaporators, condensers and expansion devices, eventually accompanied with additional heat exchangers, fans, motors and factory supplied accessories
- remote (condenser) display cabinets work with a remote refrigerating unit which is not an integral part of the display cabinet
- they can be designed for the display of chilled or frozen products
- they may be orientated as vertical, semi-vertical or horizontal equipment;
- with or without doors (also referred to as 'open' or 'closed' cabinets);

Regarding temperature, the following considerations are important:

Different temperature requirements are applied depending on the product on sale, where some require the maintenance of a constant temperature and some allow controlled temperature variations. Chilling refers to a working temperature above 0°C whereas freezing/frozen refers to a working temperature below 0°C.

A commercial refrigerator or chiller is a commercial refrigerated cabinet intended to store and maintain products at a temperature above 0°C, with a reference point at +5°C (M1 temperature class).

A commercial freezer is a commercial refrigerated cabinet intended to store and maintain products at a temperature below 0°C, with a reference point at -18°C (L1 temperature class)

Table 1. Temperature classifications of refrigerated display cabinets in ISO EN 23953.

Class	Highest temperature of warmest M-package	Lowest temperature of coldest M-package	Lowest temperature of warmest M-package
L1	-15	-	-18
L2	-12	-	-18
L3	-12	-	-15
M1	5	-1	-
M2	7	-1	-
H1	10	1	-
H2	10	-1	-
S	Special classification		

The types of refrigerated display cabinet are classified by ISO as shown in Table 2.

Table 2. ISO classification for refrigerated display cabinet families from Annex A of EN ISO 23953-2:2005. (Note classes in (parentheses) are not included in Eurovent market statistics because their market share is very low)[1].

Application	Positive temperature		Negative temperature	
	For chilled foodstuffs		For frozen & quick-frozen foodstuffs, and ice cream	
Horizontal	Chilled, serve-over-counter open service access	HC1	Frozen, serve-over-counter open service access	HF1
	Chilled, serve-over-counter with integrated-storage open service access	(HC2)		
	Chilled, open, wall site	HC3	Frozen, open, wall site	HF3
	Chilled, open, island	HC4	Frozen open, island	HF4
	Chilled, glass lid, wall site	HC5	Frozen, glass lid, wall site	HF5
	Chilled, glass lid, island	HC6	Frozen, glass lid, island	HF6
	Chilled, serve-over-counter closed service access	(HC7)	Frozen, serve-over-counter closed service access	(HF7)
	Chilled, serve-over-counter with integrated-storage closed service access	(HC8)		
Vertical	Chilled, semi-vertical	VC1	Frozen, semi-vertical	VF1
	Chilled, multi-deck	VC2	Frozen, multi-deck	(VF2)
	Chilled, roll-in	VC3		
	Chilled, glass door	VC4	Frozen, glass door	VF4
Combined	Chilled, open top, open bottom	(YC1)	Frozen, open top, open bottom	(YF1)
	Chilled, open top, glass-lid bottom	(YC2)	Frozen, open top, glass-lid bottom	(YF2)
	Chilled, glass-door top, open bottom	(YC3)	Frozen, glass-door top, open bottom	YF3
	Chilled, glass-door top, glass lid bottom	(YC4)	Frozen, glass-door top, glass-lid bottom	YF4
	Multi-temperature, open top, open bottom			(YM5)
	Multi-temperature, open-top, glass-lid bottom			(YM6)
	Multi-temperature, glass-door top, open bottom			(YM7)
	Multi-temperature, glass-door top, glass-lid bottom			(YM8)

[1] The classification codes used in this table are preceded by 'R' if the cabinet has a remote condenser and 'I' if it is an integral cabinet.

2.1 Types of refrigerated display cabinets

Examples of the principal types of refrigerated display cabinets that are treated in this report are shown in Figures 1 to 7.

Figure 1. Open-chilled vertical multi-deck remote refrigerating display cabinet (category RVC2 according to EN ISO 23953), with 7 m² TDA (left hand model), operating in temperature class M2 (-1°C to 7°C).

Figure 2. Vertical freezer (or chiller) with doors (category RVC4 or RVF4 according to EN ISO 23953).

Figure 3 Semi-vertical multi-deck chiller (category RYC1 according to EN ISO 23953).

Figure 4. Serve-over counter chiller (category IHC1 according to EN ISO 23953). Plug-in type.

Figure 5. Open remote horizontal frozen island (category RHF4 according to EN ISO 23953), with 7 m² TDA (left hand side), operating in temperature class L2 (-18°C to -12°C), using R404a as refrigerant.

Figure 6. Beverage cooler with one glass door, operating at temperature classes H1 and H2 (5°C), with a net volume of 500 litres, using R134a as refrigerant. Plug-in type.

Figure 7. Packaged horizontal ice cream freezer with lids (category IHF6 according to EN ISO 23953), with a net volume of 291 litres, operating in temperature class L1 (-23°C to -18°C), using R507 as refrigerant. Plug-in type.

2.2 Energy performance test procedures

The names of the energy performance test standards applicable to reach-in coolers are shown in Table 3.

Table 3. Energy performance test procedures used for refrigerated display cabinets and other commercial refrigeration product types.

Economy	Organisation	Standards
International	ISO	ISO EN 23953-1:2005, Refrigerated display cabinets -- Part 1: Vocabulary
		ISO EN 23953-2:2005, Refrigerated display cabinets -- Part 2: Classification, requirements and test conditions
Australia	Standards Australia	AS 1731.1:2003 Part 1: Terms and definitions
		AS 1731.9:2003 Part 9: Electrical energy consumption test
		AS 1731.14:2003 Part 14: Minimum energy performance standard (MEPS) requirements
Brazil	ABNT	ABNT NBR ISO 23953-1:2009 Expositores refrigerados Parte 1: Vocabulári (same as ISO standards)
		ABNT NBR ISO 23953-2:2009 Expositores refrigerados Parte 2: Classificação, requisitos e condições de ensaio (same as ISO standards)
Canada	CSA	CAN/CSA-C827-10:2010 Energy Performance Standard for Food Service Refrigerators and Freezers
		CAN/C657-12:2012 energy performance standard for commercial refrigerated display cabinets and merchandisers
China	Standardization Administration of China	GB 26920.1-2011 : The maximum allowable values of energy performance and energy efficiency grades of commercial refrigerating appliances - Part 1 : Refrigerated display cabinets with remote condensing unit
		GB/T 21001.3-2010: Refrigerated display cabinets - Part 3: Test rating
		GB/T 21001.1-2007: Refrigerated display cabinets - Part 1: Vocabulary
		GB/T 21001.2-2007: Refrigerated display cabinets - Part 2: Classification requirements and test conditions
Germany	DIN	DIN 18872-1:2011 Equipment for commercial kitchens – Refrigeration technology equipment - Part 1: Refrigerators and refrigerated counters, Requirements and testing”
		DIN 18872-3:2011 Equipment for commercial kitchens – Refrigeration technology equipment – Part 3: Refrigerated display cases for food distribution, Requirement and testing
EU	CEN	EN ISO 23953-1:2005, Refrigerated display cabinets -- Part 1: Vocabulary
		EN ISO 23953-2:2005, Refrigerated display cabinets -- Part 2: Classification, requirements and test conditions
India	Bureau of Indian Standards	IS 9210-1979: Refrigerated display cabinets
		IS 2167-1983: Specification for Bottle coolers
		IS 5839:2000 - Food hygiene code of practice for manufacture, storage and sale of ice cream
Japan	Japanese Standard Association	IEC 60335-2-75:2012 Household and similar electrical appliances - Safety - Part 2-75: Particular requirements for commercial dispensing appliances and vending machines
		JIS B 8631-1:2011: Refrigerated display cabinets -- Part 1: Vocabulary (English version available)
		JIS B 8631-2:2011: Refrigerated display cabinets -- Part 2: Classification, construction, characteristics and test conditions (in Japanese only)
Mexico		NOM-022-ENER/SCFI:2008: Eficiencia energética y requisitos de seguridad al usuario para aparatos de refrigeración comercial autocontenidos. Límites, métodos de prueba y etiquetado
South Africa	South African Bureau of Standards	SABS 1406:2006 Commercial refrigerated food display cabinets (replaces 1406:1998:)
US	ARI	1200-2006: Performance Rating of Commercial Refrigerated Display Merchandisers and Storage Cabinets
	ANSI	72(2005): Method of Testing Commercial Refrigerators and Freezers (Includes Interpretation 02 to ANSI/ASHRAE Standard 72-2005)
		NSF/ANSI 7-2009 NSF International Standard/ American National Standard for Food Equipment Commercial refrigerators and freezers

International standards

The predominant international test procedure is ISO EN 23953:2005 that was developed by CEN in Europe and adopted by ISO through the Vienna Agreement mechanism that links the European and International standardisation processes. Among the target economies it is used fully in Brazil, China and Europe. The test procedure used in Japan is almost identical and the test procedure used in Australia is based on the earlier version of the EN ISO standard. In addition the EN ISO standard appears to be used in South Africa in preference to the standard published by the South African Bureau of Standards. The USA and Canada essentially use the ANSI standards (the Canadian standard is equivalent to the ANSI one). Mexico use their own national standard, which is not equivalent to any of the other standards although shares some aspects in common with them.

Australian standards

The Australian standard AS 1731:2003 is a clone of the old (1994) European standard EN 441 except that as opposed to the EN-ISO 23953:2005, it includes (in the part 14) MEPS and high efficiency levels. There are some small differences in the test method, relating to the type of test packages used and to the internal lighting of the cabinet (when no night covers or automatic lighting switch is employed, the AS 1731 calls for 24 hour lighting as opposed to the EN ISO standard that calls for 12 hour lighting per day). A detailed comparison of AS 1731 with the European and USA standards is given in the "in from the cold" report (Ellis 2009).

Brazilian standards

The Brazilian national standards ABNT NBR ISO 23953-1:2009 Expositores refrigerados Parte 1: Vocabulári and ABNT NBR ISO 23953-2:2009 Expositores refrigerados Parte 2: Classificação, requisitos e condições de ensaio are fully identical to the ISO 23953:2005 standard.

Chinese standards

The Chinese voluntary national standards GB/T 21001.1-2007 and GB/T 21001.2-2007 are fully identical to the ISO 23953:2005 standard.

European standards

EN ISO 23953:2005 and its 2012 amendments are the standard for measuring total energy consumption (TEC) and total display area (TDA) for refrigerated display cabinets in Europe. It is a matter of time (and retesting of cabinets with glass doors) before the 2012 amendments will be used as well for the UK Enhanced Capital Allowance scheme (see Section 2.3). The European standards committee CEN TC 44 in 2013 developed a new Annex D "Performance and Energy Rating of Commercial Refrigerated Display Cabinets" to the standard with the intention of facilitating the application of the standard to any type of energy assessment which may be defined and based on the requirements of the EU Ecodesign Directive.

EN 441 (1994) is the predecessor to EN ISO 23953: 2005 and consists of elven parts. Prior to EN 441 the ISO 1993 (from 1973/4) was used in Europe. The content of EN 441 – and before that of ISO 1993 - has been mostly incorporated into the new EN ISO 23953. Furthermore, a number of new elements have been introduced, including:

- a scheme to divide cabinets into different categories,
- the definition of Total Display Area (TDA)
- and references to the characteristics of the climate chamber in which cabinets are tested.

Test room dimensions are of importance, as it is a "secret of the trade" that the size of the test chamber influences the results of the measurement. Smaller test chambers tend to produce better temperature and superior cabinet energy performance results, because the cold air spilling from the cabinet is not dispersed as much as in large test rooms. For the last two decades, the test room at TNO (in Apeldoorn, The Netherlands) has served as a reference test room, since all verification tests on RVC2 cabinets for the Eurovent certification scheme were performed here. Many test rooms over Europe were designed to look alike. The test room at TNO will probably be abandoned in 2014 and it is not yet clear which test lab will be used as the reference test room nor how this will affect the comparability of results produced before and after the change in labs.

The 2012 amendments to EN ISO 23953 include some additional precisions on the sensor for measuring the ambient temperature. But more importantly, a possibility was created to use alternative filler packages in the cabinet. The use of such packages is more in line with Australian/NZ and USA practices, and moreover is an answer to the scarcity of supply of the official ISO “tylose” test packages, which has been a problem for many years.

EN ISO 23953 does not apply to commercial refrigeration equipment with non-transparent doors. Such cabinets are not seen as refrigerated display cabinets, but rather as commercial service cabinets and therefore for such cabinets it is more appropriate to use a volumetric measure of efficiency than one based on the total display area. The testing of commercial service cabinets is covered by the German standard DIN 18872.

Indian standards

The Indian Standard IS 9210-1979 “Refrigerated display cabinets” is an old standard dating to the 1970s. A copy of this standard was acquired by the project team and analysed and from this it was determined that the standard is not similar to predecessors of EN ISO 23953. It applies only to frozen food cabinets and specifies test room temperatures of 32^{o}C or 43^{o}C. The test packages are made of sawdust soaked in sodium chloride, and wrapped liquid tight (dimensions correspond to those used by ISO test packages, but otherwise they are dissimilar). Locations for M-packages are designated by the manufacturer, which risks enabling gaming of the results by avoiding the necessity for designating test packs to be placed in all parts of the cabinet and thereby offering the potential to avoid unfavourable "hot spots". Product temperatures are also designated by the manufacturer (i.e. there are no defined product temperature classes). The test must run for eight hours or more, and does not have to include a defrosting period (defrosting is tested separately from temperature and energy tests).

In practice, however, it’s not thought that this standard is widely applied. Rather it is believed by the project team that cabinet technical specifications are usually copied from the originating countries (e.g. European cabinets will have EN ISO specifications) although technical energy performance specifications for Indian cabinets are not publically available.

Japanese standards

The project team acquired and analysed the JIS B 8631-1:2011: Refrigerated display cabinets standard and have found it to essentially be equivalent to the EN ISO 23953: 2005 standard.

The differences between JIS and EN ISO 23953 are very minor. A comparison is made easy by tables present in the Japanese standards, wherein all differences are listed:

- Table of appendix JA for part 1 (pages 15 - 16)
- Table of appendix JC for part 2 (pages 93 - 96)

Many of the changes are of the nature of additional explanations in the Japanese standard. The only technical differences are that in Japan, smaller test packages are defined (MS packages of 62.5 grams) and that the rated voltage is different (Japan uses 100 Volt, 50 or 60 Hz).

These differences are only likely to result in very small differences in energy performance test results between the two standards.

North American standards

ANSI/ASHRAE 72 -2005 is the official standard used in the USA for self-contained (integral) and remote commercial refrigerators and freezers with no doors or drawers.

The 1998 version of the ANSI/ASHRAE 72 standard did not cover commercial refrigeration equipment with doors but these are addressed in the 2005 version. Cabinets with doors were previously covered by the standard ANSI/ASHRAE 117-1992, which was subsequently withdrawn after being merged into the 2005 version of the ANSI/ASHRAE 72 standard.

The ANSI/AHRI STANDARD 1200 from 2010 (or the identical standard 1201 for SI units) provides guidance on how to calculate Total Energy Consumption (TEC) and Total Display Area (TDA) figures, as well as the test conditions under which ratings must be specified.

Canada also uses ANSI/ASHRAE 72, and this is specifically referenced in the Canadian Energy Performance Standard for Commercial Refrigerated Display Cabinets and Merchandisers C657-12.

In Mexico the testing requirements are also specified within the regulations for minimum energy performance standards and labelling, NOM-022-ENER/SCFI:2008: Eficiencia energética y requisitos de seguridad al usuario para aparatos de refrigeración comercial autocontenidos. Límites, métodos de prueba y etiquetado. The test method used has similarities to the EN ISO and ANSI/ASHRAE 72 test procedure but also significant differences as set out in Table 4.

Table 4. Comparison of key testing requirements under the EN ISO, ANSI/ASHRAE and Mexican test standards for reach-in coolers.

Markets	Brazil, China, EU, Japan, South Africa	Canada, USA	Mexico
Standard	EN ISO 23953	ASHRAE 72	NOM-022-ENER/SCFI
Climate	Manufacturers declared Climatic Class Mostly 25°C / 60 % RH	Dry Bulb 24 °C ± 1.0 °C Wet Bulb 18 °C ± 1.0 °C	32°C ± 1.5°C and 65% ± 5% RH
Airflow	0.2 m/s (+0/-0.1 m/s)	< 0.25 m/s across display Opening	< 0.254 m/s
Test Room Lighting	600 ± 100 lux at 1 m above floor and on continuously	Not less than 800 lux in relation to display opening	Not specified
Power Supply	± 2% of nominal value of Marked rating	± 4% of rated voltage	230 V ± 1V, 60 Hz 115 V ± 1V, 60 Hz
Product load	ISO type M Packages and ISO type Filler/Test packages	Test Packages and Filler Packages	Medium temperature: 355 ml cans Low temperature: ISO type test packages.
Test Period - Open cabinets	First test: Cabinet lighting on for 24 hours and night covers removed. Second test: Night covers removed and cabinet lighting on for 12 h followed by night covers fitted and cabinet lighting off for 12 h	24 h with all electrical components energised.	Pull down test. Minimum 24 h test period. All electrical components energised.

Table 4. Continued - Comparison of key testing requirements under the EN ISO, ANSI/ASHRAE and Mexican test standards for reach-in coolers.

Markets	Brazil, China, EU, Japan, South Africa	Canada, USA	Mexico
Standard	EN ISO 23953	ASHRAE 72	NOM-022-ENER/SCFI
Test Period - Closed cabinets	First test: Cabinet lighting on for 24 hours. Second test: Cabinet lighting on for 12 h and then cabinet lighting off for 12 h.	8 h with doors opened cyclically starting 3 hours after defrost. All electrical components energized.	Pull down test. Minimum test period 24 h without door openings. All electrical components energised.
Cabinet test Temperature	Manufacturers declared M package temperature class	Not in ASHRAE 72 but in ANSI/ARI 1200: Low temperature: Average -18°C ± 1.1°C. Medium temperature: 3.3°C ± 1.1°C Ice Cream: -26°C ± 1.1°C	Medium temp. with fan: Max 7.2°C, Min 0°C, Av 3.3°C. Med. temp. Cold plate: Max 10°C, Min -1°C, Av ≤ 5°C. Freezers: Max -18°C.
Efficiency Metric	Not applicable yet TEC/TDA (UK ECA)	Volume TDA defined in ARI 1200	Refrigerated Volume
COP	0,34 * T_0 / (T_c-T_0)	COP table	No (only integrals)

South African standards

Cabinet manufacturers in South Africa are reported to use EN – ISO 23953 as measurement standard[2] – despite the existence of the South African National Standard SANS 1406:2006 Edition 3, “Commercial refrigerated food display cabinets”. This has been confirmed by inspection of product technical information available on manufacturer websites.

2.3 Energy efficiency policies

There are a variety of policy tools applied to the energy efficiency and global warming impact of commercial refrigeration equipment that can be broadly classified into: MEPS, labelling and financial/fiscal incentives. Policies designed to address total equivalent warming impacts (TEWI) are also in place in some economies. These policies are summarised in this section.

MEPS

Australia and New-Zealand

From 1 October 2004[3], refrigerated display cabinets manufactured in or imported into Australia and New Zealand must comply with Minimum Energy Performance Standards (MEPS) requirements which are set out in AS 1731.14-2003. The scope of commercial refrigeration MEPS includes both remote and self-contained refrigerated display cabinets primarily used in commercial applications for the storage of frozen and unfrozen food. The standard also defines minimum efficiency levels for ‘High Efficiency’ refrigerated display cabinets. Only products which meet the specified efficiency levels can apply this term to promotional or advertising materials.

2 Email communication from Rainer Faustmann, Colcab PTY Ltd. (CRE manufacturer South Africa)
3 Taken from http://www.energyrating.gov.au/products-themes/refrigeration/commercial-refrigeration/meps/

The Minimum Energy Performance Standards (MEPS) for commercial refrigeration are set out in AS1731.14-2003 as total energy consumption per total display area (TEC/TDA) in kWh/day/square metre for various unit types; values are shown in Table 5 for remote condensing cabinets.

Table 5. Maximum energy consumption (total energy consumption/total display area: TEC/TDA) allowable under minimum energy performance standards for remote cabinets in Australia and New Zealand (note, blank = no requirement).

Type of remote cabinet	Other features	TEC/TDA (kWh/day•m^2)
RS 1	Unlit shelves	12.55
	Lit shelves	17.76
RS 2	Unlit shelves	12.73
	Lit shelves	16.98
RS 3	Unlit shelves	14.84
	Lit shelves	18.39
RS 4	Solid door	–
	Glass door	9.73
RS 5	Solid door	–
	Glass door	–
RS 6	Gravity coil	14.21
	Fan coil	14.16
RS 7	Gravity coil	–
	Fan coil	14.79
RS 8	Gravity coil	12.25
	Fan coil	13.19
RS 9	Gravity coil	–
	Fan coil	12.09
RS 10	High	–
	Medium	–
	Low	18.67
RS 11		38.13
RS 12		66.33
RS 13	Solid sided	19.48
	Glass sided	19.58
RS 14	Solid sided	15.49
	Glass sided	19.29
RS 15	Solid door	–
	Glass door	37.08
RS 16	Solid door	–
	Glass door	40.56
RS 17	Solid door	–
	Glass door	–
RS 18		48.58
RS 19		36.15
RS 20		–

Table 6 shows the requirements for self-contained refrigerated cabinets. If cabinets meet the "high efficiency" specifications set out in Tables 7 and 8 they are entitled to be designated as high efficiency units.

Table 6. Maximum energy consumption (total energy consumption/total display area: TEC/TDA) allowable under minimum energy performance standards for self-contained cabinets in Australia and New Zealand (note, blank = no requirement).

Type of self-contained cabinet	M-package temperature class[a]	TEC/TDA (kWh/day•m^2)	Type of self-contained cabinet	M-package temperature class	TEC/TDA (kWh/day•m^2)
HC1	M1	11.50	HF1	L1	–
	M2	11.50		L2	–
HC2	M1	–	HF2	L1	–
	M2	–		L2	–
HC3	M1	–	HF3	L1	–
	M2	–		L2	–
HC4	M1	15.50	HF4	L1	26.50
	M2	15.50		L2	26.50
HC5	M1	–	HF5	L1	–
	M2	–		L2	–
HC6	M1	–	HF6	L1	8.00
	M2	–		L2	8.00
VC1	M1	37.50	VF1	L1	–
	M2	27.00		L2	–
VC2	M1	27.00	VF2	L1	–
	M2	25.50		L2	–
VC3	M1	–	VF3	L1	–
	M2	–		L2	–
VC4	M1	Solid door: 17.00; Glass door: 17.00	VF4	L1	Solid door: 44.00; Glass door: 44.00
	M2	Solid door: 17.50; Glass door: 17.50		L2	Solid door: 39.00; Glass door: 39.00
YC1	M1	–	YF1	L1	–
	M2	–		L2	–
YC2	M1	–	YF2	L1	–
	M2	–		L2	–
YC3	M1	–	YF3	L1	–
	M2	–		L2	–
YC4	M1	–	YF4	L1	–
	M2	–		L2	–

a M-package temperature class according to AS1731.6 Clause 5.

Table 7. Maximum energy consumption (total energy consumption/total display area: TEC/TDA) allowable under minimum energy performance standards AS 1731.9 and AS 1731.12 under climate Class 3 conditions for 'high-efficiency' remote display cabinets in Australia and New Zealand (note, blank = no requirement).

Type of remote cabinet	Other features	TEC/TDA (kWh/day•m^2)
RS 1	Unlit shelves	8.37
	Lit shelves	10.66
RS 2	Unlit shelves	8.49
	Lit shelves	11.32
RS 3	Unlit shelves	10.32
	Lit shelves	12.26
RS 4	Solid door	–
	Glass door	6.77
RS 5	Solid door	–
	Glass door	–
RS 6	Gravity coil	9.88
	Fan coil	9.85
RS 7	Gravity coil	–
	Fan coil	9.86
RS 8	Gravity coil	8.52
	Fan coil	9.17
RS 9	Gravity coil	–
	Fan coil	8.06
RS 10	High	–
	Medium	–
	Low	12.99
RS 11		26.52
RS 12		46.14
RS 13	Solid sided	12.99
	Glass sided	13.62
RS 14	Solid sided	11.45
	Glass sided	12.86
RS 15	Solid door	–
	Glass door	27.41
RS 16	Solid door	–
	Glass door	29.98
RS 17	Solid door	–
	Glass door	–
RS 18		39.75
RS 19		29.57
RS 20		–

Table 8. Maximum energy consumption (total energy consumption/total display area: TEC/TDA) allowable under minimum energy performance standards AS 1731.9 and AS 1731.12 under climate Class 3 conditions for 'high-efficiency' self-contained cabinets in Australia and New Zealand (note, blank = no requirement).

Type of self-contained cabinet	M-package temperature class[a]	TEC/TDA (kWh/day•m^2)	Type of self-contained cabinet	M-package temperature class	TEC/TDA (kWh/day•m^2)
HC1	M1	8.50	HF1	L1	–
	M2	8.50		L2	–
HC2	M1	–	HF2	L1	–
	M2	–		L2	–
HC3	M1	–	HF3	L1	–
	M2	–		L2	–
HC4	M1	11.40	HF4	L1	19.50
	M2	11.40		L2	19.50
HC5	M1	–	HF5	L1	–
	M2	–		L2	–
HC6	M1	–	HF6	L1	5.90
	M2	–		L2	5.90
VC1	M1	27.60	VF1	L1	–
	M2	20.60		L2	–
VC2	M1	19.90	VF2	L1	–
	M2	18.80		L2	–
VC3	M1	–	VF3	L1	–
	M2	–		L2	–
VC4	M1	Solid door: 7.30; Glass door: 10.70	VF4	L1	Solid door: 32.40; Glass door: 32.40
	M2	Solid door: 7.30; Glass door: 10.70		L2	Solid door: 28.70; Glass door: 28.70
YC1	M1	–	YF1	L1	–
	M2	–		L2	–
YC2	M1	–	YF2	L1	–
	M2	–		L2	–
YC3	M1	–	YF3	L1	–
	M2	–		L2	–

a M-package temperature class according to AS1731.6 Clause 5.

The test procedures for commercial refrigeration are the specified parts AS 1731. When measured in accordance with AS 1731.9 and AS 1731.12 the energy consumption of a remote or self-contained refrigerated cabinet shall not exceed a specified value as set out in Table 5 for remote condensing cabinets and Table 6 for self-contained refrigerated cabinets.

For the purpose of testing compliance, tests shall be conducted under climate Class 3 conditions, with lighting and anti-sweat heaters running for the duration of the test period, unless controlled by a time-clock, smart sensor or similar automatic device. Where night-covers are supplied as a permanent fixture of the cabinet, the test shall be conducted as described in AS 1731.9, Section 4.

Reference should be made to the relevant parts of AS 1731 for detailed conditions and test methods.

Brazil

Brazil currently has no MEPS in place for any type of commercial refrigeration equipment.

China

China applies MEPS to remote condensing refrigerated display cabinets as set out in Table 9. The product categories that these MEPS apply to are specified in Table 10 and are identical to the remote condenser product categories used in the Australian standard AS 1731. Staff at CNIS reported to the project team that they are considering development of MEPS for self-contained refrigerated display cabinets.

Table 9. Maximum allowable energy consumption (ECC_{max}) of medium- and low-temperature refrigerated display cabinets with remote condensing unit in China.

	Cabinet type[a]		ECC_{max} in type 3 climate,[b] by M-pack temperature classification (kWh.day•m^2)		
			M1	M2	H1, H2
Medium-temperature cabinets	RS1	Non-illuminated shelf	12.55	11.04	9.72
		Illuminated shelf	15.98	14.06	12.37
	RS2	Non-illuminated shelf	12.73	11.20	9.86
		Illuminated shelf	16.98	14.94	13.15
	RS3	Non-illuminated shelf	14.84	13.06	11.49
		Illuminated shelf	17.63	15.51	13.65
	RS4	Solid door	–	–	–
		Glass door	9.73	8.56	7.53
	RS5	Solid door	–	–	–
		Glass door	–	–	–
	RS6	Direct cooling evaporator (calandria)	14.21	12.50	11.00
		Fan coil	14.16	12.46	10.97
	RS7	Direct cooling evaporator (calandria)	–	–	–
		Fan coil	14.79	13.02	11.45
	RS8	Direct cooling evaporator (calandria)	12.25	10.78	9.49
		Fan coil	13.19	11.61	10.21
	RS9	Direct cooling evaporator (calandria)	–	–	–
		Fan coil	12.09	10.64	9.36
	RS10	High	–	–	–
		Medium	–	–	–
		Low	18.67	16.43	14.46

Table 9. continued. Maximum allowable energy consumption (ECC_{max}) of medium- and low-temperature refrigerated display cabinets with remote condensing unit in China.

	Cabinet type[a]		ECC_{max} in type 3 climate,[b] by M-pack temperature classification (kWh.day•m^2)		
			M1	M2	H1, H2
Low-temperature cabinets	RS11		38.13	30.50	24.40
	RS12		66.33	53.06	42.45
	RS13	Solid envelope	19.48	15.58	12.47
		Glass envelope	19.58	15.66	12.53
	RS14	Solid envelope	17.17	13.74	10.99
		Glass envelope	18.49	14.79	11.83
	RS15	Solid door	–	–	–
		Glass door	37.08	29.66	23.73
	RS16	Solid door			
		Glass door	40.56	32.45	25.96
	RS17	Solid door	–	–	–
		Glass door	–	–	–
	RS18		48.58	38.86	31.09
	RS19		36.15	28.92	23.14
	RS20				

Abbreviations: EEC_{max} = maximum allowable energy efficiency co-efficient (total energy consumption [kWh/day]/total display area [m^2]).

a See Table {A1 & 2} for RS classification codes.

b As specified in GB/T21001.2-2007.

Table 10. Types of refrigerated display cabinets with remote condensing units in China.

Cabinet type	Model	Description	Classification		
Medium-temperature cabinets					
Open multi-level upright (high)	RS1	Medium-temperature-multi-level cabinet, air curtain length 1.5–1.9 m; cabinet height 2.2–2.5 m, depth 0.6–1.2 m	Non-illuminated shelf	Illuminated shelf	
Open multi-level upright (medium)	RS2	Medium-temperature-multi-level cabinet, air curtain length 1.0–1.5 m; cabinet height 1.8–2.19 m, depth 0.6–1.2 m	Non-illuminated shelf	Illuminated shelf	
Open multi-level upright (low)	RS3	Medium-temperature-multi-level cabinet, air curtain length 0.8–1.2 m; cabinet height 0–1.79 m, depth 0.6–1.2 m	Non-illuminated shelf	Illuminated shelf	
Enclosed self-service storage	RS4	Multiple shelves, glass door; cabinet height 1.8–2.2 m, depth 0.6–1.2 m	Solid door	Glass door	
Enclosed self-service storage: lower counter	RS5	Multiple shelves, glass door; cabinet height 0–1.79 m, depth 0.6–1.2 m	Solid door	Glass door	
With front single-layer flat glass	RS6	Medium-temperature single-level cabinet with flat glass at the front and sliding door at the back; cabinet height 1.25–1.4 m, depth 0.8–1.2 m; two subtypes according to the arrangement of the coils of its evaporator	Direct-cooling calandria	Fan coil	
With front double- or multi-layer flat glass	RS7	Medium-temperature double- or multi-level cabinet with flat glass at the front and sliding door at the back; cabinet height 1.25–1.4 m, depth 0.8–1.2 m; two subtypes according to the arrangement of the coils of its evaporator	Direct-cooling calandria	Fan coil	
With front single-layer curved glass	RS8	Medium-temperature-single-level cabinet with curved glass at the front and sliding door at the back; cabinet height 1.25–1.4 m, depth 0.8–1.2 m; two subtypes according to the arrangement of the coils of its evaporator	Direct-cooling calandria	Fan coil	
With front double- or multi-layer curved glass	RS9	Medium-temperature-double- or multi-level cabinet with curved glass at the front and sliding door at the back; cabinet height 1.25–1.4 m, depth 0.8–1.2 m; two subtypes according to the arrangement of the coils of its evaporator	Direct-cooling calandria	Fan coil	
Upright with glass structure visible on four sides	RS10	Cabinet height 2.2–2.5 m (high), 1.8–2.9 m (medium), 0–1.79 m (low)	High	Medium	Low
Low-temperature cabinets					
Open multi-level upright (medium)	RS11	Low-temperature multi-level cabinet, air curtain length 1.0–1.5 m; cabinet height 1.8–2.19 m, depth 0.6–1.2 m	No classification		
Open multi-level upright (low)	RS12	Low-temperature multi-level cabinet, air curtain length 0.6–1.0 m; cabinet height 0–1.79 m, depth 0.6–1.2 m	No classification		
Single-width open	RS13	Low-temperature self-service open cabinet with horizontal air curtain (length 0.75–0.85 m) at the opening	With solid envelope	With glass envelope	
Double-width open	RS14	Low-temperature self-service open cabinet with horizontal air curtain (length 2 × (0.75–0.85 m)) at the opening	With solid envelope	With glass envelope	
Enclosed self-service storage (high)	RS15	Low-temperature, cabinet height 2.2–2.8 m, depth 0.6–1.2 m	Solid door	Glass door	
Enclosed self-service storage (medium)	RS16	Low-temperature, cabinet height 1.8–2.19 m, depth 0.6–1.2 m	Solid door	Glass door	
Enclosed self-service storage (low)	RS17	Low-temperature, cabinet height 0–1.79 m, depth 0.6–1.2 m	Solid door	Glass door	
Composite with glass door in upper part and open lower part	RS18	Cabinet height 1.8 – 2.2 m, with glass door in the upper part and open lower part	No classification		
Enclosed self-service storage with glass structure visible on four sides (high)	RS19	Low-temperature, glass door, cabinet height 2.2–2.8 m, depth 1.9–2.1 m	No classification		
Enclosed self-service storage with glass structure visible on four sides (medium)	RS20	Low-temperature, glass door, cabinet height 1.8–2.19 m, depth 1.9–2.1 m	No classification		

Europe

The European Union is currently developing Ecodesign requirements for all types of non-customised commercial refrigeration equipment. Separate studies are being done for merchandising reach-in coolers and vending machines (Ecodesign Lot 12) and professional refrigeration and freezing equipment (ENTR Lot 1). The Lot 12 study is expected to be completed in early 2014 and new Ecodesign policy measures proposed shortly afterwards. Proposed regulations for professional refrigeration and freezing equipment (including commercial service cabinets) were submitted to inter-service consultation within the European Commission in June 2013. The preliminary Lot 12 work includes analysis supplied by the project team working on this study.

India

India currently has no MEPS in place for any type of commercial refrigeration equipment.

Japan

Japan currently has no MEPS in place for refrigerated display cabinets but does have "Top Runner" requirements for commercial service cabinets.

Mexico

The MEPS applied in Mexico are set out in Table 11. These only apply to self-contained (i.e. integral) cabinets and thus there are no requirements for remote condensing cabinets.

Table 11. Maximum allowable energy consumption for self-contained commercial refrigeration[a] in Mexico

Device type	Maximum consumption (kWh/L • day)	Capacity range (L)	Maximum permitted tolerance in energy consumption (kWh/L • day)
Vertical coolers			
Forced air	0.2463× V −0.4537	50–1200	0.0099
Cold plate	1.0489 × V −0.8763	50–1200	0.0021
Horizontal coolers			
Forced air	4.5922 × V −1.0162	100–500	0.0083
Cold plate	1.0489 × V −0.8763	100–500	0.0045
Upright freezers			
Glass door and forced air	0.0725 × V −0.1136	100–500	0.0358
Glass door and cold plate	0.2378 × V −0.4189	200–1500	0.0111
Horizontal freezers			
Solid door	0.0353 × V −0.2142	100–700	0.0087
Solid door, medical	0.0767 × V −0.2839	100–700	0.0119
Glass door	0.0767 × V −0.2839	100–500	0.0131
Closed cabinet			
Medium temperature	0.1555 × V −0.2915	200–1200	0.0197
Low temperature	0.103 × V −0.1228	200–1200	0.0431
Ice pack store	0.2245 × V −0.5674	250–2500	0.0026

a Testing must be performed at room temperature of 40 °C and 65% relative humidity.

USA

In the USA equipment class designations are coded using a combination of (i) a family code, (ii) an operating mode code and (iii) a rating temperature code; the codes are separated by full points.

(i) Family codes: HCS, horizontal solid doors; HCT, horizontal transparent doors; HZO, horizontal open; SOC, service over counter; SVO, semi-vertical open; VCS, vertical solid doors; VCT, vertical transparent doors; VOP, vertical open.

(ii) Operating mode codes: RC, remote condensing; SC, self-contained (integral).

(iii) Rating temperature codes: I, ice cream temperature (−15 °F; −26.1 °C); L, low temperature (0 °F; −17.8°C); M, medium temperature (38 °F; 3.3 °C).

Tables 12 and 13 set out the definitions of types of commercial refrigeration equipment configurations applied in US MEPS for commercial refrigeration equipment. It is worth noting that the most popular type of product, bottle coolers (classified as VCT.SC.M) is not included in this list but is covered in a separate regulation.

The scope of the US MEPS regulations for commercial refrigerators and freezers also excludes walk in cabinets.

Table 12. Definitions and configurations for commercial refrigerators and freezers in the USA

Type	Description	
	Doors	Other information
Vertical open (VOP)	No	Air-curtain angle ≥0 degrees and <10 degrees from the vertical
Semi-vertical open (SVO)	No	Air-curtain angle ≥10 degrees and <80 degrees from the vertical
Horizontal open (HZO)	No	Air-curtain angle ≥80 degrees from the vertical
Vertical closed (VC)	Hinged or sliding	Door angle <45 degrees
Horizontal closed (HC)	Hinged or sliding	Door angle ≥45 degrees

Source: DOE 2009.

The MEPS applied to commercial refrigeration equipment in the USA are shown in Table 14.

Table 13. Commercial refrigeration equipment in the USA, by category

Equipment category	Condensing unit configuration	Equipment family	Operating temperature (°F[a])	Equipment class designation
Remote condensing commercial refrigerators, freezers and refrigerator-freezers	Remote	Vertical open	≥32 <32	VOP.RC.M VOP.RC.L
		Semi-vertical open	≥32 <32	SVO.RC.M SVO.RC. L
		Horizontal open	≥32 <32	HZO.RC.M HZO.RC.L
		Vertical closed transparent	≥32 <32	VCT.RC.M VCT.RC.L
		Horizontal closed transparent	≥32 <32	HCT.RC.M HCT.RC.L
		Vertical closed solid	≥32 <32	VCS.RC.M VCS.RC.L
		Horizontal closed solid	≥32 <32	HCS.RC.M HCS.RC.L
		Service over counter	≥32 <32	SOC.RC.M SOC.RC.L
Self-contained commercial refrigerators, freezers and refrigerator-freezers without doors	Self-contained	Vertical open	≥32 <32	VOP.SC.M VOP.SC.L
		Semi-vertical open	≥32 <32	SVO.SC.M SVO.SC.L
		Horizontal open	≥32 <32	HZO.SC.M HZO.SC.L
Commercial ice cream freezers[b]	Remote	Vertical open	≤−5	VOP.RC.I
		Semi-vertical open		SVO.RC.I
		Horizontal open		HZO.RC.I
		Vertical closed transparent		VCT.RC.I
		Horizontal closed transparent		HZT.RC.I
		Vertical closed solid		VCS.RC.I
		Horizontal closed solid		HCS.RC.I
		Service over counter		SCO.RC.I
	Self-contained	Vertical open		VOP.SC.I
		Semi-vertical open		SVO.SC.I
		Horizontal open		HZO.SC.I
		Vertical closed transparent		VCT.SC.I
		Horizontal closed transparent		HCT.SC.I
		Vertical closed solid		VCS.SC.I
		Horizontal closed solid		HCS.SC.I
		Service over counter		SOC.SC.I

Source: DOE 2009.

a 32 °F = 0 °C.

b 'Ice cream freezer' is defined in 10 CFR 431.62 as a commercial freezer designed to operate at or below −5 °F (−21 °C) and for the storing, display or dispensing of ice cream.

Table 14. Standard levels for commercial refrigerators and freezers (including display and solid-door cabinets) manufactured in or imported into the USA, applied on or after 1 January 2012

Equipment class			Standard level (kWh/day)
Operating mode	Rating temperature	Family	
Remote condensing	Medium	VOP	0.82 x TDA + 4.07
		SVO	0.83 x TDA + 3.18
		HZO	0.35 x TDA + 2.88
		VCT	0.22 x TDA + 1.95
		SOC	0.51 x TDA + 0.11
		HCT	0.16 x TDA + 0.13
		VCS	0.11 x TDA + 0.26
		HCS	0.11 x TDA + 0.26
	Low	VOP	2.27 x TDA + 6.85
		HZO	0.57 x TDA + 6.88
		VCT	0.56 x TDA + 2.61
		SVO	2.27 x TDA + 6.85
		HCT	0.34 x TDA + 0.26
		VCS	0.23 x TDA + 0.54
		HCS	0.23 x TDA + 0.54
		SOC	1.08 x TDA + 0.22
	Ice cream	VOP	2.89 x TDA + 8.70
		SVO	2.89 x TDA + 8.70
		HZO	0.72 x TDA + 8.74
		VCT	0.66 x TDA + 3.05
		HCT	0.40 x TDA + 0.31
		VCS	0.27 x TDA + 0.63
		HCS	0.27 x TDA + 0.63
		SOC	1.26 x TDA + 0.26
Self-contained	Medium	VOP	1.74 x TDA + 4.71
		SVO	1.73 x TDA + 4.59
		HZO	0.77 x TDA + 5.55
	Low	HZO	1.92 x TDA + 7.08
		VOP	4.37 x TDA + 11.82
		SVO	4.34 x TDA + 11.51
	Ice cream	VCT	0.67 x TDA + 3.29
		VCS	0.38 x TDA + 0.88
		HCT	0.56 x TDA + 0.43
		VOP	2.89 x TDA + 8.70
		SVO	2.89 x TDA + 8.70
		HZO	0.72 x TDA + 8.74
		SOC	1.76 x TDA + 0.36
		HCS	0.38 x TDA + 0.88

Source: DOE 2009. *Abbreviations:* TDA = total display area in ft^2 according to ARI Standard 1200-2006, Appendix C).

California

California applies MEPS to refrigerated display cabinets which predate those applying in the rest of the USA as shown in Table 15 and which are based on a volumetric measure as opposed to total display area. California MEPS were superseded by USA MEPS beginning January 1, 2012.

The scope of the MEPS regulations, are the same as for the US Federal regulations except the latter include one additional category of appliance (Reach-in cabinets, pass-through cabinets, and roll-in or roll-through cabinets that are "pulldown" refrigerators – transparent door - 0.126V+ 3.51 maximum daily consumption in kWh/day) which does not feature in the California standard. The Californian regulations also cover bottle coolers (the IVC4 / VCT.SC.M class products) in the same regulation as for other retail display cabinets.

Table 15. Standard levels for commercial refrigerators and freezers (including display and solid-door cabinets) manufactured in or imported into California

Appliance	Doors	Maximum Daily Energy Consumption (kWh)			
		March 1, 2003	August 1, 2004	January 1, 2006	January 1, 2007
Reach-in cabinets, pass-through cabinets, and roll-in or roll-through cabinets that are refrigerators; and wine chillers that are not consumer products	solid	0.125 V+4.22	0.125 V+2.76	0.10 V+2.04	0.10 V+2.04
	transparent	0.172 V+5.78	0.172 V+4.77	0.172 V+4.77	0.12 V+3.34
Reach-in cabinets, pass-through cabinets, and roll-in or roll-through cabinets that are freezers (except ice cream freezers)	solid	0.398 V+2.83	0.398 V+2.28	0.40 V+1.38	0.40 V+1.38
	transparent	0.940 V+5.10	0.940 V+5.10	0.940 V+5.10	0.75 V+4.10
Reach-in cabinets, pass-through cabinets, and roll-in or roll-through cabinets that are freezers that are ice cream freezers	solid	0.398 V+2.83	0.398 V+2.28	0.398 V+2.28	0.39 V+0.82
	transparent	0.940 V+5.10	0.940 V+5.10	0.940 V+5.10	0.88 V+0.33
Reach-in cabinets that are refrigerator-freezers and that have and adjusted volume (AV) of 5.19ft3 or greater	solid	0.273 AV+2.63	0.273 AV+1.65	0.273 AV+1.65	0.27 AV-0.71
Reach-in cabinets that are refrigerator-freezers and that have and adjusted volume (AV) less than 5.19ft3	solid or transparent			0.70	0.70
Refrigerated canned and bottled beverage vending machines when tested at 90°F ambient temperature except multi-package units	Not applicable			0.55(8.66+0.009x C)	0.55(8.66+0.009x C)
Refrigerated canned and bottled beverage vending machines when tested at 75°F ambient temperature	Not applicable			0.55(8.66+0.009x C)	0.55(8.66+0.009x C)

V=total volume (ft^3)

AV=Adjusted Volume = 1.63xfrezzer volume (ft^3)+refrigerator volume(ft^3)

C = rated capacity (number of 12 ounce cans)

Source: BIO IS study

South-Africa

SABS 1406:1999: 'commercial refrigerated food display cabinets'

This standard provides a test methodology and a minimum energy performance standard, based on the gross capacity of the cabinet. The standard specifies requirements for three refrigerated display cabinet types and two climate classes for the storage, or sale, of frozen and fresh foods, and liquids in containers, and intended for operation on a three-phase 440 V power supply or on a single-phase power supply not exceeding 250 V phase to neutral.

The energy requirements of this standard cover energy consumption, test conditions and energy consumption test.

Labelling

China and Mexico are the only economies to apply mandatory energy labelling for refrigerated display cabinets. Australia applies a kind of high efficiency designation scheme and the USA operates voluntary energy labelling through Energy Star.

Australia

Australia has no energy labelling requirements in place for refrigerated display cabinets but does permit products to be designated as high efficiency units if they meet the requirements set out in Tables 7 and 8.

Brazil

Brazil currently has no energy labels in place for commercial refrigeration equipment.

China

China operates a mandatory energy label for remote condensing refrigerated display cabinets whose specifications are set out in Table 16.

Table 16. Energy efficiency grades of refrigerated display cabinets with remote condensing units in China

Energy efficiency index (ECC/ECC_{max} × 100%)	Energy efficiency grade
<=55%	1
55% < 65%	2
65% < 80%	3
80% < 90%	4
90% < 100%	5

Abbreviations: EEC_{max} = maximum allowable energy efficiency co-efficient (total energy consumption [kWh/day]/total display area [m^2]).

The energy efficiency grade of a particular refrigerated display cabinet shall be judged according to the results of the ECC test and Table 16. The energy efficiency index EEI is calculated from:

$EEI = ECC / ECC_{max} \times 100\%$

Where:

EEI (energy efficiency index) has no dimension

ECC = the energy consumption coefficient of a refrigerated display cabinet with remote condensing (kWh/24h/m^2) (this is equivalent to a TEC/TDA metric)

ECC_{max} = the maximum allowable value of the energy consumption coefficient of a refrigerated display cabinet with remote condensing unit (kWh/24h/m^2).

Europe

Europe is developing Ecodesign requirements for refrigerated display cabinet units and it is possible recommendations regarding energy labelling could also be formulated as part of the same policy process.

India

India currently has no energy labels in place for commercial refrigeration equipment.

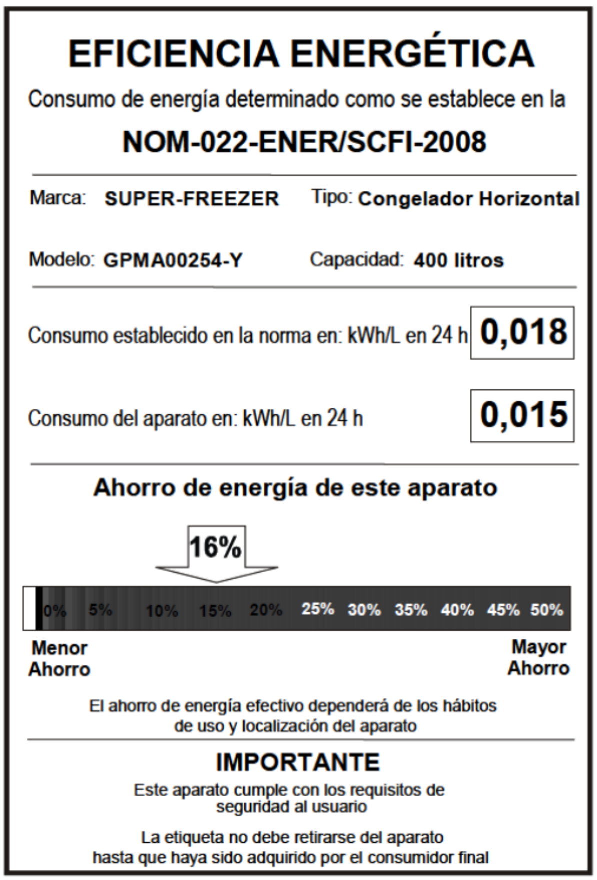
Japan

Japan currently has no energy labels in place for reach-in-coolers.

Mexico

Mexico operates a mandatory energy label for self-contained refrigerated display cabinets as shown in Figure 8. All eligible products are required to be certified and registered by CONUEE.

Figure 8. The Mexican energy label for self-contained RDC units



South Africa

South Africa currently has no energy labels in place for reach-in-coolers.

USA

The USA does not apply mandatory energy labels for refrigerated display cabinets units under its Federal Trade Commission operated labelling scheme, but voluntary Energy Star labelling specifications have been developed as shown in Table 17.

Table 17. ENERGY STAR Maximum Daily Energy Consumption requirements for commercial food-grade refrigerators and freezers

	Product volume (cubic feet)	Refrigerators	Freezers
Vertical cabinets			
Solid door	0 < V <15	≤ 0.089V + 1.411	≤ 0.250≤ + 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 + 10416	≤ 0.58V + 6.333
Glass door	0 < V <15	≤ 1.118V + 1.382	≤ 0.607V + 0.893
	15 ≤V < 30	≤ 0.140V + 1.050	≤ 0.733V – 1.000
	30 ≤ V < 50	≤ 0.88V + 2.625	≤ 0.250V + 13.500
	50 ≤V	≤ 0.110V + 1.500	≤ 0.450V + 3.500
Chest cabinets			
Solid or glass door		≤ 0.125V + 0.475	≤ 0.270V + 0.130

The interior volume (V) of a refrigerator or freezer shall be calculated by AHAM Standard Household Refrigerators/Household Freezers (ANSI/AHAM HRF-1-2004)[4].

The maximum daily energy consumption (MDEC) of mixed solid/glass door cabinets (designed with two or more compartments contained in a single cabinet with different exterior door types - i.e., one is glass and one is solid - on the same side of the cabinet) shall be the sum of all individual compartment MDEC values. For purposes of mixed solid/glass door cabinets, compartments are defined by the volume associated with the different exterior door types. The interior of these compartments may or may not be physically separated.

The volume of each individual compartment shall be measured, and its MDEC limit determined, based on the compartment’s volume and door type, as listed in Table 17 above. The sum of the volumes of each compartment shall be equivalent to the total AHAM volume of the cabinet.

Financial and fiscal incentives and refrigerant orientated policies (JRC 2013)

A number of countries apply financial or fiscal incentives to encourage the adoption of low global warming impact refrigerants in commercial refrigeration equipment. In some cases incentives are also applied to encourage procurement of higher energy efficiency products.

Australia

Australia applies taxes on anthropogenic greenhouse gases as well as minimum energy performance requirements for refrigerated display cabinets.

Under the Clean Energy Future (CEF) legislation, the Australian Government introduced a carbon charge to the import of synthetic greenhouse gases including HFCs as of 1 July 2012. They provide a calculator for the import levy and equivalent carbon price[5].

[4] Definition from ANSI/ASHRAE Standard 72-2005, Method of Testing Commercial Refrigerators and Freezers, American Society of Heating, Refrigerating, and Air-Conditioning Engineers, Inc. 2005

Denmark

Denmark has one of the most stringent combinations of HFC taxation and a partial ban. The complete Danish refrigeration industry is subject to a gradual phase out of fluorinated greenhouse gases. New refrigeration systems requiring more than 10 kg of fluorinated refrigerant have been banned since 1 January 2007[6]. This ban has had a huge impact on the systems implemented especially in supermarkets, where practically all new supermarkets are built with trans-critical CO_2 systems. The ban is further complemented with a tax on the import of fluorinated greenhouse gases.

Following a request by Denmark in February 2012, the European Commission has issued a decision allowing the country to maintain more stringent national legislation than the EU F-gas regulation, authorising a continuation of the national ban on new products containing certain F-gases.

France

France is introducing more stringent requirements set out in the EU F-gas regulation, by setting the target at a minimum refrigerant charge of 2 kg instead of 3 kg as specified in the original EU framework document. From 4 July 2009, anyone having installed or intending to install refrigeration systems including cooling fluids needs to have an attestation of capacity.

Recently, the French government indicated that it will examine the possibility of an F-gas tax in the "Roadmap for the Environmental Transition" published after the Grenelle de l'environnement (Environmental Conference) held on 14-15 September 2012 in Paris. The document states that "concerning the fight against climate change, the [French] government […] will perform assessment studies on the appropriateness of levying a tax on fluorinated greenhouse gases used as refrigerants […]".

In January 2012, the association of French retailers (Fédération des Entreprises du Commerce et de la Distribution – FCD) made a commitment to roll out doors on fridges to all store formats – hypermarkets, supermarkets and convenience stores.

Germany

The Federal Ministry for the Environment operates an incentive scheme that covers 25% of the net investment costs for new or existing commercial refrigeration plants using natural refrigerants. Funding for existing systems being afterwards more energy-efficient but still running on conventional refrigerants will be supported by only 15% of the net investment costs. This scheme may not still be operational as it was frozen in 2010.

Norway

Norway operates a tax and refund scheme for HFCs applying to both imports as well as national production, whether in bulk or in products. Even though Norway is not an EU member state, it belongs to the European Economic Area (EEA), meaning that all environmental and internal market legislation of the EU applies to Norway.

Spain

Spain is understood to be operating some kind of tax rebate for companies applicable to environmental spending which may also apply to investment in energy saving and efficiency measures. It is not clear if the draft law from 2009 has passed into a formal law and/or if there was any modification.

[5] See http://www.environment.gov.au/atmosphere/ozone/sgg/equivalentcarbonprice/calculator.html

[6] Statutory Order no. 552 of 2 July 2002

Sweden

Sweden limits the refrigerant charge per refrigerated display cabinet system to some 30 or 40 kg. Tax burdens on HFC, following the example of Norway, are under consideration and final discussion in the Swedish parliament.

Switzerland

Substances stable in air, including HFCs, have been regulated in Switzerland since July 2003 through the Ordinance on Chemical Risk Reduction (ORRChem). This HFC regulation encompasses licensing, reporting, leak checks, servicing and end-of-life requirements for equipment containing more than 3kg of such refrigerants. Moreover, the voluntary Minergie-label operated by the Swiss Federal Office for Energy certifies energy performance of HVAC and refrigeration systems including refrigerated display cabinets. Many retailers require Minergie labelling for refrigerated display cabinets and are especially applying this to investments in efficient CO_2 cooled systems.

In October 2012, ORRChem was amended after 9 years of implementation. The previous mandatory authorisation scheme has been replaced by a ban from placing on the market several types of stationary refrigeration and air-conditioning systems using F-gas refrigerants. For commercial refrigeration, this means a ban on systems using F-gas refrigerants for

- sub-zero C cooling with a cooling capacity of more than 30 kW,
- above zero C cooling with a cooling capacity of more than 40 kW;
- combined systems with a cooling capacity of more than 40 kW for plus cooling and 8 kW for minus cooling.

United Kingdom

The UK operates an enhanced capital allowance scheme (ECA) which provides businesses with enhanced tax relief for investments in equipment, including refrigerated display cabinets that satisfy specified energy-saving criteria. Qualified products are listed in a database.[7]

2.4 Energy efficiency of product markets

Data availability

Data on the energy efficiency of products on the various national markets of interest has been gathered for: Australia, China, the EU, Japan, Mexico, South Africa, the UK and the USA. Some indications of product performance are also available for China and Mexico, based on the prescriptions in the existing MEPS and energy labelling regulations. It was not possible to obtain data for Brazil or India because neither country requires the energy performance of reach-in coolers to be measured and producers are not in the habit of disclosing such performance even if the data has been measured. Thus the energy performance of products on both markets is unknown, but is thought likely to be towards the lower efficiency end of the international market due to the lack of transparency. The reported data for the other markets (Australia, China, EU, Japan, UK, South Africa, USA/California) is drawn from product databases and is particularly extensive for Australia, EU and USA (California). This is unsurprising as these economies have either set, or are in the process of setting, product energy efficiency requirements. An extensive database of integral cabinets was available from Mexico but no data on remote cabinets was available. By contrast the EU database only includes information on remote cabinets, which have been subject to a voluntary energy labelling scheme since 1997. Some industry sourced information on the average performance of integral cabinets was available too, but is thought to be out of date.

[7] https://etl.decc.gov.uk/etl/site/etl/browse-etl/refrigeration.html

The reach-in cooler energy performance data available for Australia, China, Europe, Japan, Mexico and the USA is summarised as follows:

- for Australia, data on commercial refrigeration equipment can be found on the Australian energy rating website www.energyrating.gov.au. The Australian "In from the cold" report (Ellis 2009) contains graphical data from the MEPS registrations for Australia up to 2009. From these graphs, average TEC/TDA values per cabinet category can be estimated. The data from the 2012 IEA-4E mapping document concerning Australian refrigerated display cabinets (IEA 2012d) unfortunately does not make a distinction between open-type and glass-covered type ice cream merchandiser cabinets
- energy performance data for China is only available for the very small number (about 16) of products that are registered in the national energy labelling database (http://www.energylabel.gov.cn/NewsMore.aspx?para=uncc_bagg). This data only covers remote condenser refrigerated display cabinets and is not likely to be very representative of the market as a whole as the number of products contained is so small; however, the minimum efficiency of remote condenser units is bounded by MEPS and hence some aspects of the market performance can be derived from the regulations in place
- for Europe, energy performance data is available from the Eurovent Certification refrigerated display cabinet programme, published at www.eurovent-certification.com. This database only contains commercial refrigeration equipment with remote condensing units and only concerns products sold under the four brands currently participating in the certification programme. The data from the 2012 IEA-4E mapping document concerning UK refrigerated display cabinets (IEA2012b) unfortunately does not make a distinction between open-type and glass-covered type ice cream merchandiser cabinets
- data on the performance of Japanese commercial refrigeration equipment are not generally publically available, however, one major manufacturer (Fukushima) publish an on-line catalogue which contains TEC and TDA data, as well as other technical specifications for all their products (a total of over 60 products)
- in Mexico, the national energy agency, CONUEE, have supplied access to a database of over 100 integral cabinets registered under the Mexican energy labelling scheme. No data on remote units were available.
- for the USA, data are available from the California Energy Commission's appliance efficiency database at www.appliances.energy.ca.gov. The data on commercial refrigeration equipment concerns both "plug-in" (integral) appliances and commercial refrigeration equipment with remote condensing units, for a total of 6947 cabinets. The data from the 2012 IEA-4E mapping document concerning USA refrigerated display cabinets (IEA 2012c) unfortunately uses cabinet volume as functional measure instead of TDA (Total Display Area), and is therefore not as useful for international comparisons.

Energy efficiency metrics

Most economies have adopted the TEC over TDA metric as the measure of energy efficiency of open refrigerated display cabinet units and for most types of glass door cabinets (currently all glass door cabinets in the EU and Australia). Economies using this metric include:

- Australia
- Brazil
- China
- EU
- Japan
- South Africa
- USA (in the most recent Federal MEPS regulations except for bottle coolers)

In the case of India it is not yet clear what metric, if any, is used to define refrigerated display cabinet efficiency. California and Mexico use a TEC over volume metric.

There are many differences in how the TEC/TDA values are derived, as discussed in section 2.6, which affect the degree of direct comparability of values measured under different test procedures. Section 2.6 also discusses comparisons between TEC/TDA and TEC/volume based efficiency metrics.

Example of energy efficiency data

Table 18 shows an illustration of the refrigerated display cabinet energy performance values found for the EU market. The highest efficiency products in the European market (as found in the Eurovent database, which does not cover all products on the market) are shown in Table 18. Also shown are values that Eurovent themselves report are the “average” of the European market, however, these so called average values are known to be based on data that can be over a decade old and these are therefore unreliable indicators of current average efficiency levels. Eurovent defined their market average efficiency values for remote cabinets in 1997 (based on cabinets manufactured and sold in Finland, France, Germany, Italy, Sweden and the United Kingdom) and for integral cabinets in 2001 (based on cabinets manufactured and sold in Finland, France, Germany, Italy and Spain). The values for integral cabinets have been updated since they were first defined in 2001; however, the values for remote units have not been. Taking into account an average energy consumption improvement of 2.5 % per year (see Figure 9), the project team estimates the Eurovent 2013 values should be corrected such that they become 40 % lower for remote cabinets.

Table 19 shows a summary of the average TEC/TDA data found for all economies as reported according to test results made under the national or regional test procedure. Note, all except the Californian and US TSD values are directly comparable as the test procedures used are essentially harmonised with the EN-ISO test procedure.

Figure 9 shows how the energy efficiency of one of the most common classes of refrigerated display cabinet has evolved in Europe from 2005 to 2012. The efficiency metric reported in the data is TEC over display cabinet length, which is an historical metric and is used in preference to TEC/TDA to enable the full temporal comparison to be made.

Table 18. Eurovent database European average and best performer total energy consumption/total display area (TEC/TDA) for remote display cabinets (March 2013)

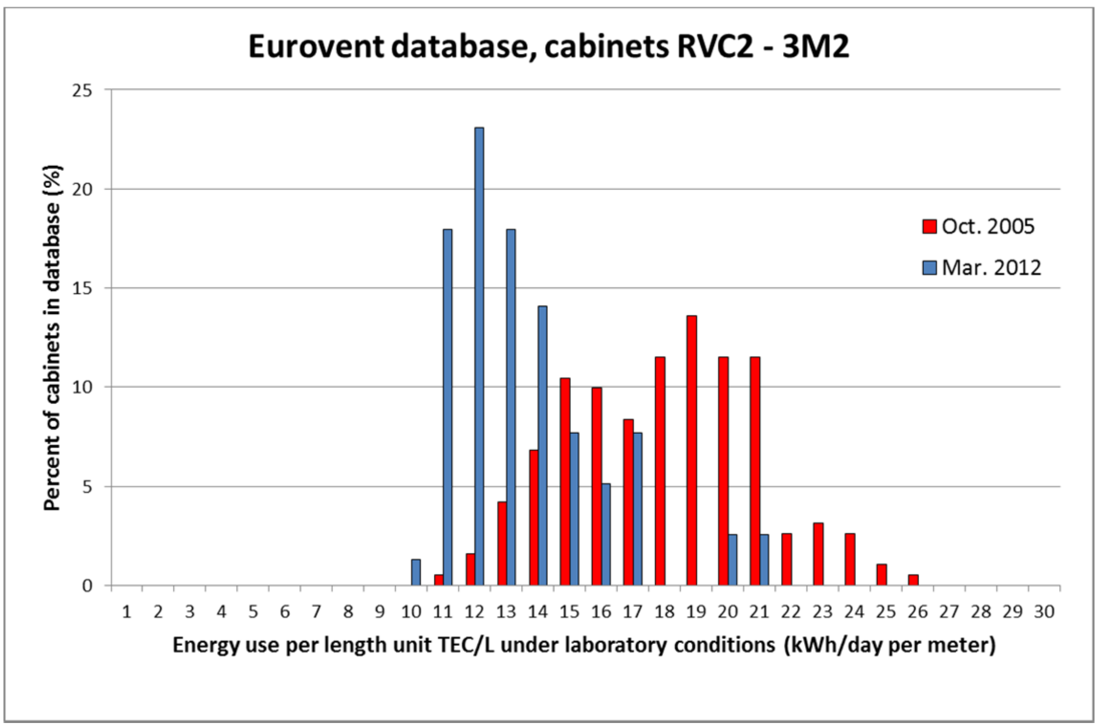
ISO 23953	Temperature	TEC/TDA (kWh/day•m²)	
cabinet type	Class	Average	Best performer
RVC1, RVC2	3H	10.1	5.3
	3M2	12.3	6.2
	3M1	13.4	7.4
	3M0	14.5	8.4
RVC3	3H	13.8	No data
	3M2	16.0	7.25
RVF1	3L3	29.0	No data
RVF4	3L1	28.5	20.5
RVC4	3H	6.1	3.2
	3M2	7.4	3.7
	3M1	8.0	4.9
	3M0	8.7	6.8
RHC1	3H	6.2	3.7
	3M2	6.7	3.9
	3M1	7.2	4.2
RHF1	3L3	21.0	13.7
RHC3, RHC4	3H	No data	4.6
	3M2	5.5	4.9
	3M1	5.8	5.9
	3M0	6.2	No data
RHF3, RHF4	3L1	15.0	No data
	3L2	14.0	9.5
	3L3	13.0	7.1
RHC5, RHC6	3H	4.3	No data
	3M2	4.7	No data
	3M1	5.0	No data
RHF5, RHF6	3L1	12.0	7.8
	3L2	11.2	9.9
	3L3	10.4	5.3
RYF3	3L2	30.0	25.9
	3L3	29.0	24.3
RYF4	3L2	28.5	No data
	3L3	27.6	24.4

Table 19. Average total energy consumption/total display area (kWh/m2) for remote and integral display cabinets in various economies

Type EN-ISO	Australia		California		China		EU (Eurovent)		Japan		RSA		USA TSD
	kWh/m2	No.	kWh/m2	No.	kWh/m2	No.	kWh/m2	No.	kWh/m2	No.	kWh/m2	No.	kWh/m2
RVC2	10.3	209	7.4	139	28.8	4	7.5	237	5.7	45	9.9	48	9.3
RHF4	14.3	71	7.6	6	10.8	8	10.7	26	12.9	20	16.5	12	7.7
IVC4	10.1	517	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	2.9
IVC2	14.8	211	9.0	10	NA	NA	15.1	NA	NA	NA	15.6	2	21.4
IHF4	18.9	38	NA	NA	NA	NA	20	NA	NA	NA	NA	NA	26.9
IHF6	6.6	213	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	6.0

Sources: Australia energy rating database (2013), California CEC database (2013), China energy label database (2013), EU Eurovent database (March 2013), Japan (Fukushima catalogue, 2013), South Africa (manufacturer internet data 2013), USA – USDOE Technical Support Document spreadsheets

Figure 9. Evolution of the distribution of efficiency of EU RDC units (RVC2 products tested at 3M2 condition) from 2005 to 2012



2.5 Stocks and sales

Data on stocks and sales are challenging to come by, however, detailed time-series estimates on the stocks and sales of commercial refrigeration equipment have been acquired for the USA (TSD 2011) (Table 20) and for Japan (JARN 2012) (Table 21). Data on the stock of units on the Australian market for selected years is available from Ellis (2009) and IEA 4E (2012).

Table 20. Stocks of refrigerated display cabinets in the USA in 2010−12 (USDOE 2011) (values estimated after 2010)

	VOP	VCT	VCS	SVO	SOC	HZO	HCS	PD	Total
2010	354 326	639 744	683 577	286 664	68 648	186 768	174 893	186 887	2 581 506
2011	345 603	623 995	666 749	279 607	66 958	182 170	170 588	182 286	2 517 957
2012	350 644	633 096	676 473	283 685	67 934	184 827	173 076	184 945	2 554 679

Abbreviations: HCS = horizontal closed solid; HZO = horizontal open; PD = Pull-Down Cases; SOC = serve-over counter; SVO = semi-vertical open; VCS = vertical closed solid; VCT = vertical closed transparent; VOP = vertical open

Table 21. Sales of refrigerated display cabinets (JRAIA 2013) and estimated stocks in Japan 1999−2012 (derived)

	Shipments			Stocks		
	Integral units	Remote condensing units	Total	Integral units	Remote condensing units	Total
1999	294 457	94 241	388 698	2 744 896	898 244	3 643 140
2000	291 621	106 147	397 768	2 678 312	912 549	3 590 861
2001	280 706	82 889	363 595	2 602 157	899 946	3 502 103
2002	267 956	104 249	372 205	2 494 005	885 687	3 379 692
2003	193 794	107 004	300 798	2 325 029	853 824	3 178 853
2004	195 164	106 139	301 303	2 158 321	828 532	2 986 853
2005	190 430	104 554	294 984	2 033 030	810 930	2 843 960
2006	183 778	101 998	285 776	1 897 906	807 221	2 705 127
2007	164 663	96 472	261 135	1 768 112	809 452	2 577 564
2008	159 502	85 811	245 313	1 635 993	789 116	2 425 109
2009	150 605	84 168	234 773	1 505 892	790 395	2 296 287
2020	161 025	82 934	243 959	1 398 961	769 080	2 168 041
2011	178 666	97 584	276 250	1 383 833	759 660	2 143 493
2012	166 673	131 420	298 093	1 355 342	784 941	2 140 283

Remote condenser refrigerated display cabinets

In the case of the EU, Eurovent have estimated the unit sales and stocks of remote condenser refrigerated display cabinets, Table 22 (JRC 2013).

In the case of other markets, sales value data for remote condenser refrigerated display cabinets is available from a Freedonia market report[8] (Tables 23 and 24). This is then extended backwards in time (i.e. prior to 1999) by assuming the same annual average growth rates applied pre 1999 as occurred from 1999 to 2004; the resulting sales value time series is then converted into a volume

[8] http://www.mzweb.com.br/metalfrio2008/web/conteudo_en.asp?idioma=1&conta=44&tipo=19837#3

(i.e. number of units) time series by assuming that the average price and type of refrigerated display cabinet units is the same in each market as in the EU (Table 25). The exception to this is the USA, where the average unit cost is derived from data in the TSD (2011) and applied to derive unit sales estimates. These unit volume sales time series are then converted into an estimate of the stock time series through the application of a simple stock model which assumes the average refrigerated display cabinet product service life is 8 years. This produces the refrigerated display cabinet stock values shown in Table 26.

Table 22. Sales and stocks of remote condenser refrigerated display cabinets in the EU from 2004 to 2010 (JRC 2013)

	2004	2005	2006	2007	2008	2009	2010
Average EU-25 estimations of sales linear extrapolation for 2008-2010 (Eurovent)	225 884	231 400	239 073	245 255	219 723	224 395	196 488
Estimated EU-25 stock (Eurovent)	2 032 959	2 082 600	2 151 654	2 207 295	2 266 642	2 325 849	2 385 055

Note: Eurovent is an association of European HVAC and refrigeration equipment manufacturers

Table 23. Sales of remote condenser refrigerated display cabinets worldwide in 1999, 2004 and 2009 by value (Freedonia[9])

	Sales (US$, millions)			Average annual growth rate	
	1999	2004	2009	1999–2004	2004–2009
USA	700	625	679	−2.2%	1.7%
Canada	65	75	80	2.9%	1.3%
Mexico	200	255	231	5.0%	−2.0%
Western Europe	935	1 080	1 150	2.9%	1.3%
Russia	60	80	105	5.9%	5.6%
Other Eastern European countries	100	115	145	2.8%	4.7%
Japan	545	460	420	−3.3%	−1.8%
China	45	150	280	27.2%	13.3%
India	40	60	90	8.4%	8.4%
Other Asian countries	350	430	565	4.2%	5.6%
Brazil	90	100	140	2.1%	7.0%
Rest of Latin America	90	102	130	2.5%	5.0%
Turkey	25	30	40	3.7%	5.9%
Rest of Africa/Middle East	115	125	165	1.7%	5.7%
Total	3 360	3 687	4 220	1.9%	2.7%

[9] http://www.mzweb.com.br/metalfrio2008/web/conteudo_en.asp?idioma=1&conta=44&tipo=19837#3

Table 24. Share of global remote condenser display cases market worldwide in 1999, 2004 and 2009 by value (Freedonia)

	1999	2004	2009
United States	20.8%	17.0%	16.1%
Canada	1.9%	2.0%	1.9%
Mexico	6.0%	6.9%	5.5%
Western Europe	27.8%	29.3%	27.3%
Russia	1.8%	2.2%	2.5%
Other Eastern European countries	3.0%	3.1%	3.4%
Japan	16.2%	12.5%	10.0%
China	1.3%	4.1%	6.6%
India	1.2%	1.6%	2.1%
Other Asian countries	10.4%	11.7%	13.4%
Brazil	2.7%	2.7%	3.3%
Rest of Latin America	2.7%	2.8%	3.1%
Turkey	0.7%	0.8%	0.9%
Rest of Africa/Middle East	3.4%	3.4%	3.9%
Total	100.0%	100.0%	100.0%

Table 25. Estimated sales (thousands of units) of remote condenser refrigerated display cabinets worldwide 1999–2009 (derived from numerous sources including Freedonia and EU data)

	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009
United States	144	141	138	135	132	129	131	133	135	137	140
Canada	13	14	14	15	15	15	16	16	16	16	16
Mexico	41	43	45	48	50	52	51	50	49	48	47
Western Europe	192	198	204	210	216	222	225	228	231	234	237
Russia	12	13	14	15	16	16	17	18	19	20	22
Other Eastern European countries	21	21	22	22	23	24	25	26	27	28	30
Japan	112	108	105	101	98	95	93	91	90	88	86
China	9	12	15	19	24	31	35	40	45	51	58
India	8	9	10	10	11	12	13	15	16	17	19
Other Asian countries	72	75	78	81	85	88	93	99	104	110	116
Brazil	19	19	19	20	20	21	22	24	25	27	29
Rest of Latin America	19	19	19	20	20	21	22	23	24	25	27
Turkey	5	5	6	6	6	6	7	7	7	8	8
Rest of Africa/Middle East	24	24	24	25	25	26	27	29	30	32	34
Total	691	701	713	726	741	759	777	798	820	843	868

The unit sales estimates derived in Table 25 for remote condenser refrigerated display units can be partially corroborated through comparison of the results with the unit sales values available for the EU (Eurovent), Japan (JRAIA) and the USA (TSD 2011). The results are found to be in good agreement which gives some confidence in the approach. Similarly, the stock estimates in Table 26 can be compared to other estimates for the EU (Eurovent) and the US (TSD 2011) and again seem to be in good agreement. For example, in the case of the EU the results produced by this approach give values that are within 2% of those projected by Eurovent despite being derived from totally different data sources and with a completely different approach.

In addition to this data, comprehensive commercial refrigeration equipment import and export data have been gathered for each of the target economies from the UNCTAD database. From this it is clear the EU and China are the predominant producers and exporters of commercial refrigeration equipment globally.

Table 26. Estimated stock (thousands of units) of remote condenser refrigerated display cabinets worldwide 1999–2009 (derived from numerous sources)

	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009
United States	1 214	1 228	1 238	1 242	1 241	1 235	1 229	1 222	1 216	1 209	1 208
Canada	108	111	114	117	121	124	128	131	134	137	139
Mexico	307	323	339	356	373	392	408	421	431	438	442
Western Europe	1 547	1 592	1 639	1 687	1 736	1 787	1 835	1 882	1 925	1 967	2 005
Russia	89	95	100	106	112	119	126	133	141	149	158
Other Eastern European countries	166	171	176	181	186	191	197	203	210	218	227
Japan	970	975	975	971	962	949	933	914	893	869	847
China	38	49	62	79	100	128	158	192	230	271	317
India	55	59	64	70	76	82	89	97	105	114	123
Other Asian countries	553	576	600	625	652	679	709	741	776	814	856
Brazil	153	157	160	163	167	170	175	181	188	196	206
Rest of Latin America	151	155	159	163	167	171	176	182	188	195	203
Turkey	40	42	43	45	46	48	50	52	55	57	60
Rest of Africa/Middle East	199	203	206	210	213	217	221	227	234	243	253
Total	5 591	5 734	5 875	6 014	6 152	6 292	6 434	6 578	6 726	6 878	7 045

There are even less market data available on the share of remote condenser reach-in coolers by product type. For the purposes of the energy stock modelling reported in section 2.9 the share of product sub-types assumed in each economy was estimated as follows:

Australia – product shares are assumed to be proportional to the number of products by type in the www.energyrating.gov.au database

EU – assumed to match product sub-type shares in the Eurovent database

USA – assumed to match product sub-type shares in the National Impact Analysis (TSD 2011)

Japan – assumed to match the share of product sub-types in the Fukushima catalogue

Brazil, China, India, RSA – assumed to match product sub-type shares in the EU

Mexico – assumed to match product sub-type shares in the USA

Some of these assumptions are rather arbitrary but there is a reasonable degree of similarity in the type of products found across all markets and hence using the large product databases as templates for economies where market shares are less well known is a reasonable first approximation. There is also some evidence supporting a link in the product types found in the Brazilian, Chinese, Indian and South African markets with those found in the EU (although the Chinese market also has some product type similarities with the Japanese market) and similarly between the Mexican and US markets.

Integral reach-in-coolers

In the case of the EU, Eurovent have estimated the unit sales and stocks of integral refrigerated display cabinets destined for use in supermarkets, Table 27 (JRC 2013).

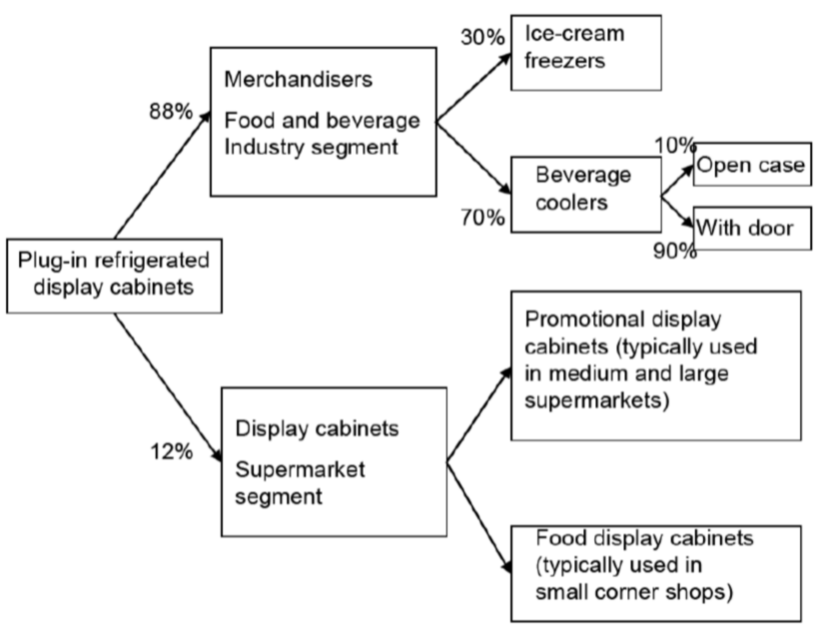
Table 27. Sales and stocks of integral refrigerated display cabinets destined for supermarkets in the EU from 2004 to 2010 (JRC 2013)

	2004	2005	2006	2007	2008	2009	2010
Average EU-25 estimations of sales linear extrapolation for 2008-2010 (Eurovent)	144000	154000	165000	176500	189000	202000	216000
Estimated EU-25 stock (Eurovent)	720000	777000	825000	882500	945000	1010000	1080000

Note: Eurovent are an association of European HVAC and refrigeration equipment manufacturers

Figure 10 shows estimated unit sales shares of integral reach-in coolers by type in the EU from which it is clear that the values in Table 27 are just 12% of the total shipments by value.

Figure 10. Estimated share of plug-in refrigerated display cabinet sales by product type in the EU
Source: **BIOS (2007).**



In the case of other markets, sales value data for integral reach-in coolers are available from the Freedonia market report[10], Table 28. As was done for the remote condenser units, this is then extended backwards in time (i.e. prior to 1999) by assuming the same annual average growth rates applied pre 1999 as occurred from 1999 to 2004; the resulting sales value time series is then converted into a volume (i.e. number of units) time series by assuming that the average price and type of refrigerated display cabinet units is the same in each market as in the EU (Table 29). Again, the USA is treated differently as the average unit cost is derived from data in the TSD (2011) and applied to derive unit sales estimates (note the US and EU average integral reach-in cooler prices are quite similar). These unit volume sales time series are then converted into an estimate of the stock time series through the application of a simple stock model which assumes the average integral reach-in cooler service life is 8 years. This produces the integral reach-in cooler stock values shown in Table 30.

Table 28. Sales of integral reach-in coolers worldwide in 1999, 2004 and 2009 by value (Freedonia[11])

	Sales (US$, millions)			Average annual growth rate	
	1999	2004	2009	1999–2004	2004–2009
USA	329	352	404	1.4%	2.8%
Canada	31	42	48	6.7%	2.4%
Mexico	184	214	202	3.1%	-1.1%
Western Europe	501	550	618	1.9%	2.4%
Russia	35	45	55	5.2%	3.9%
Other Eastern European countries	54	59	78	1.8%	5.9%
Japan	320	261	220	-4.0%	-3.4%
China	26	85	147	26.3%	11.5%
India	24	34	47	7.7%	6.7%
Other Asian countries	206	244	296	3.5%	3.9%
Brazil	83	84	123	0.3%	7.9%
Rest of Latin America	83	85	114	0.7%	5.9%
Turkey	15	17	21	3.0%	4.2%
Rest of Africa/Middle East	154	169	193	1.9%	2.7%
Total	2043	2242	2566	1.9%	2.7%

The unit sales estimates derived in Table 29 for integral reach-in coolers can be partially corroborated through comparison of the results with the unit sales estimates available for the EU (Eurovent), Japan (JRAIA) and the USA (TSD 2011). The results are found to be in good agreement for both Japan and the USA but to produce lower estimated sales than is implied by the Eurovent data for sales to supermarkets converted to whole EU stocks on an assumption that these sales account for 12% of the total. In fact other sources imply the sales volumes projected by the approach set out above are more realistic for the EU so it seems that the 12% to volume sales to supermarkets assumption is more likely to be a 12% by value figure, which would bring the two estimates into line as the average size and price of supermarket destined integral reach-in coolers is higher than for other market segments.

[10] http://www.mzweb.com.br/metalfrio2008/web/conteudo_en.asp?idioma=1&conta=44&tipo=19837#3
[11] http://www.mzweb.com.br/metalfrio2008/web/conteudo_en.asp?idioma=1&conta=44&tipo=19837#3

Table 29. Estimated sales (thousands of units) of integral reach-in coolers worldwide 1999–2009 (derived from numerous sources including Freedonia and EU data)

	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009
United States	368	373	378	383	389	394	405	416	428	440	452
Canada	34	36	39	42	44	47	48	50	51	52	53
Mexico	206	212	218	225	232	239	236	234	231	229	226
Western Europe	560	571	582	593	604	615	630	645	660	676	692
Russia	39	42	44	46	48	51	53	55	57	59	62
Other Eastern European countries	60	61	62	63	64	66	69	73	78	82	87
Japan	359	344	331	317	305	292	283	273	264	255	246
China	30	37	47	60	75	95	106	119	132	147	164
India	26	28	31	33	35	38	41	43	46	49	53
Other Asian countries	230	238	247	255	264	273	284	295	307	319	332
Brazil	93	93	93	93	94	94	101	109	118	127	137
Rest of Latin America	93	93	94	94	95	96	101	107	114	120	127
Turkey	16	17	17	18	19	19	20	21	22	23	23
Rest of Africa/Middle East	172	176	179	182	186	189	194	200	205	211	216
Total	2286	2322	2361	2405	2454	2509	2572	2640	2712	2789	2872

In order to estimate the share of integral reach-in cooler sales by sub-type for the purposes of the energy stock modelling reported in section 2.9 a similar approach is followed as for the remote condenser units, i.e.:

Australia – product shares are assumed to be proportional to the number of products by type in the www.energyrating.gov.au database

USA – assumed to match product sub-type shares in the National Impact Analysis (TSD 2011)

Japan – assumed to match the share of product sub-types in the Fukushima catalogue

EU – assumed to match product sub-type shares in Figure 10

Brazil, China, India, RSA – assumed to match product sub-type shares in the EU

Mexico – assumed to match product sub-type shares in the USA

Table 30. Estimated stock (thousands of units) of integral reach-in coolers worldwide 1999–2009 (derived from numerous sources)

	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009
United States	2975	3053	3127	3198	3266	3330	3396	3464	3534	3606	3684
Canada	240	257	274	292	312	333	353	373	391	409	426
Mexico	1644	1695	1747	1801	1856	1913	1962	2002	2034	2057	2071
Western Europe	4687	4775	4865	4957	5050	5145	5245	5350	5460	5576	5697
Russia	293	308	324	341	358	377	396	415	435	454	475
Other Eastern European countries	503	512	521	531	540	550	562	578	597	619	646
Japan	3103	3116	3112	3091	3055	3002	2937	2858	2767	2664	2566
China	125	158	199	252	318	401	493	593	702	820	946
India	179	193	208	224	241	260	279	300	322	345	370
Other Asian countries	1815	1878	1943	2011	2081	2153	2230	2310	2394	2483	2576
Brazil	824	826	828	830	833	835	844	862	887	922	966
Rest of Latin America	811	816	822	827	833	838	849	865	887	915	949
Turkey	132	136	140	144	148	153	158	163	169	175	181
Rest of Africa/Middle East	1442	1469	1496	1524	1553	1582	1613	1647	1683	1721	1762
Total	18773	19191	19607	20023	20444	20874	21318	21780	22261	22764	23314

2.6 Benchmarking of product efficiency: comparison across different test procedures

In order to facilitate the comparability of efficiency policies in Australia, Brazil, China, the EU, India, Japan, Mexico, South Africa and the USA this project sets out to:

- Identify the national test procedures applied in the target economies and their equivalence to other commonly used international or national test procedures (section 2.2)
- Examine similarity and differences in how the efficiency metrics are derived and applied in the different economies
- Conduct an initial comparison of the test procedures, and identification of potential issues that are likely to affect the comparability of nominal test results
- Compare the differences in the testing procedures and protocols to assess the expected impact on rated energy performance associated with variations in: testing conditions, testing methods, calculation methods for efficiencies, uncertainty of measurements, tolerances, etc.

This section sets out an analysis of the issues above for the principal categories of reach-in coolers.

Reach-in-cooler test standards for Europe (EN ISO 23953) and for the USA (ASHRAE 72) are different in many aspects. Many other test standards worldwide can be regarded as closely related to one of these two standards and thus understanding how test results recorded under the EU and USA standards are related is of primary importance for benchmarking. Once this is achieved test results from other standards can then usually be related to either the US or EU standard.

An overview of measurement and rating standards for reach-in coolers is given in the scoping study for Commercial Refrigerating Equipment (Klinckenberg & Puddle 2012). This study gives a detailed view of the differences between the USA and European measurement standards (Chapter 9, Table 6, page 24). A similar overview is given in the Australian “In from the cold – strategies to increase the energy efficiency of non-domestic refrigeration in Australia & New Zealand” report (Table 6, page 22) (Ellis 2009) and a highly detailed comparison is in RDTL (2012). The most thorough analysis is provided in the recent SEAD study (Ellis 2013).

The IEA study on benchmarking of refrigerated display cabinets (IEA 2012a) contains a benchmarking study for glass door cabinets and ice cream freezers. The benchmark reports for the USA, UK, Canada and Australia only consider data on self-contained (integral) cabinets, not on the more prevalent remote condensing commercial refrigerating equipment. Furthermore, the applicability of the results is further constrained because the internal volume is taken as the functional metric in the benchmarking reports, whereas total display area (TDA) is a much more common measure for functionality and TEC/TDA is the most widely used efficiency metric for most types of retail display cabinet. This is because, the vertical cabinets in the benchmark reports are of the glass-door type only (and are mostly concerned with bottle coolers) and do not include the open-fronted type which are one of the more common refrigerated display cabinet product types. Lastly, no distinction is made in the IEA benchmarking reports between open type and glass-lid type (integral) freezer islands, which makes it difficult to compare the results with either open-type freezer islands or other freezer islands.

Conversion between EN 23953 and ASHRAE 72

There is no officially approved conversion method between TEC/TDA values measured under the European and USA measurement standards. The differences of importance in the EN ISO and ASHRAE standards are listed in Table 6 of the CLASP scoping study (Klinckenberg & Puddle, 2012) and also RDTL (2012) as well as the more recent SEAD study (Ellis 2013). Some of these differences have a predictable effect on the measurement results, whereas others are harder to estimate but are also of a lesser importance. The major factors to correct for are differences in:

- the loading configuration
- loading material
- the test room temperature
- product temperature
- door opening regime
- lighting regime.

An attempt at creating a conversion can be done in several ways: experimental, analytical or combined (experimental & analytical). In the following paragraphs, a conversion will be made for MT (medium temperature) multi-deck cabinets and LT (low temperature) open-island cabinets. These cabinet types are the most commonly used cabinets, and are also often referenced in related studies. The conversion formulae presented below are derived expressly for the sole purposes of this study and while they may be suitable for approximate comparisons of market average efficiency levels and of policy settings they are not suitable for the conversion of specific product energy performance values for product rating purposes.

Experimental conversion factors for differences in loading configuration and loading material

In principle if an experimentally derived conversion method were to be established and used, many cabinets would need to be tested under the two different standards. Comparison of the test results should then allow systematic relationships between the test results to be determined. These relationships would be expected to vary depending on the type of cabinet, and therefore sufficient test results would need to be available for each type of cabinet for the results to be statistically meaningful. How finely the different types would need to be distinguished is difficult to say in advance, but it is very probable that the cabinets would need to be distinguished not only according to their “family” but also according to their product temperature classes for reliable relationships to be established. Altogether, testing would need to be extensive, and thus costly and time consuming (a single test of one cabinet – e.g. for verification of its energy performance under the Eurovent certification scheme - takes two weeks to do and costs several thousand dollars to test).

From measurements made by CEN/TC 44/WG1[12] and shared with the project team, the impact of the differences in product temperatures due to the differences in the cabinet loading and test package type can be evaluated. Adjustments can be made analytically for other differences such as ambient and specified product temperature. Table 31 shows how the averaged measured energy performance related results vary from the testing of identical cabinets in accordance with the loading and test materials specified according to the ASHRAE standard and with the loading and test materials specified according to the EN ISO standard.

Table 31. Comparison of temperature and heat extraction rate results of testing with loading and test materials according to ASHRAE 72 versus EN 441 (EN ISO 23953)

	ASHRAE compared to EN ISO		
	Average temperature	Peak temperature	Heat extraction rate
Cooling cabinets (medium temperature)	0.7 °C higher	0.1 °C lower	7.8% higher
Freezing cabinets (low temperature)	4.4 °C lower	9.6 °C lower	7.5% lower

Abbreviations: LT = low temperature; MT = medium temperature.

Analytical conversion for test room temperature & temperature of the load

From an analytical perspective differences in ambient test conditions (temperature, relative humidity and airspeed) can be compensated for by using theoretical corrections. Differences in specified product temperatures can also be analytically compensated for. In Europe, energy measurements may be made under different climate classes, but the most widely used is climate class 3 (25ºC, 60% R.H.). In the USA however, the prescribed test condition is 24ºC and 56.4% R.H. (relative humidity). This means that the "load" on the cabinet is higher for the EN ISO test at identical product temperatures, and therefore it is to be expected that the Heat Extraction Rate (HER, or cooling capacity) is higher. For the EN ISO climate class 3 test condition the HER measured under the EN ISO standard will be about 5% higher for MT appliances and 2.5% higher for LT appliances than when measuring under the ANSI/ASHRAE standard.

Under the American rating standard ANSI/AHRI 1200 & 1201, the average test package ("product") temperature is prescribed at -26ºC for ice cream applications, -18ºC for LT applications and +3.3ºC for MT applications, whereas in the European test method the test package temperatures should lie in a prescribed range of temperatures. The average test package temperature is not always presented In EN ISO test results in which case it can be estimated using the values presented in Table 32, which are derived from empirical test results measured in European test labs.

Table 32. Estimated average M-package temperature (°C) for each EN ISO M-package temperature class

	M-package temperature class							
	3H1	3H2	3M2	3M1	3M0	3L1	3L2	3L3
Estimated average temperature (°C)	+5.5	+4.5	+3.0	+2.0	+1.5	−16.5	−15.0	−13.5
ANSI/AHRI 1200 average temperature (°C)	+3.3	+3.3	+3.3	+3.3	+3.3	−18.0	−18.0	−18.0

From Table 32 we can see that comparable "product temperatures" between EN ISO and ANSI/ASHRAE can be found for cabinets tested at the EN ISO 3M2 (MT) condition.

[12] CEN/TC 44/WG1 (refrigerated display cabinets) N 62 (January 2005)

Measured H.E.R. (cooling capacity) for Medium Temperature (MT) cabinets

For a typical remote multi-deck open chilled cabinet (RVC2) it is estimated that the Heat Extraction Rate (cooling capacity) measured under the ASHRAE and EN ISO 23953 standards (climate class 3) are equal within 5 %, and temperatures are equal within 1 ^{o}C. The difference in Heat Extraction Rate due to test materials and loading configuration is on average cancelled out by the lower test room temperature, when product temperatures are comparable i.e. for cabinets tested at the EN ISO class 3M2. Thus, the measured H.E.R. (cooling capacity) between ASHRAE and EN ISO class 3M2 for remote multi-deck cabinets is about equal.

For integral (plug-in) multi-deck MT cabinets, this means that the energy consumption for the compressor measured under EN ISO is about equal to the value that is measured under ASHRAE. The total energy consumption (TEC) value measured under EN ISO will then be about 5% lower than the TEC value evaluated under ASHRAE, as lighting is applied for 24 hours under ASHRAE instead of 12 hours under EN ISO.

Measured H.E.R. (cooling capacity) for Low Temperature (LT) cabinets

For low temperature cabinets, the average product temperature measured under ANSI/ASHRAE is 4.4 ^{o}C lower than when measured under EN ISO (Table 30). From Table 31 we can see that we can then compare cabinets designated as class 3L3 under EN ISO with LT cabinets tested under ANSI/ASHRAE. We must take into account that for open island type LT remote cabinets the H.E.R. (cooling capacity) measured under ASHRAE is 7.5 % lower than when measured under EN ISO (see Table 30, we must thus correct the EN ISO measured H.E.R. value by a factor 0.925 to make a comparison).

For integral (plug-in) open island LT cabinets, this means that the energy consumption for the compressor measured under ANSI/ASHRAE is about 7.5% lower than that measured under EN ISO. The direct energy consumption (fans, lighting, defrost etc.) will not be different. The total energy consumption (TEC) value measured under EN ISO will therefore be about 6% higher than the TEC evaluated under ANSI/ASHRAE.

Daily energy consumption for remote cabinets (LT and MT).

The calculation of daily compressor or refrigeration energy consumption (CEC or REC) from the measured heat extraction rate H.E.R. differs between the AHRI and EN ISO methodology. With an identical cooling capacity and evaporating temperature, the calculated daily energy consumption for refrigeration is much higher under the EN ISO standard than under the ANSI/AHRI standard; see the two equations below and an illustration of how they affect the calculated CEC or REC in Table 33.

ANSI/AHRI 1201 (§ 5.2.1) states: $CEC = [H.E.R. \bullet (t - t_{dt})] / (COP \bullet 1000)$ - where the COP is given as a function of temperature in Table 1 on page 6 of the standard.

EN ISO 23953 (§ 5.3.6.3.3) states: $REC = [H.E.R. \bullet (t - t_{dt})] \bullet (308.15 - T) / (0.34 \bullet T)$

The value $t - t_{dt}$ = 24 hours in both cases and T is the evaporating temperature in Kelvin.

Modern MT cabinets typically operate with evaporating temperatures of between -10 ^{o}C and 0 ^{o}C. For multi-deck cabinets in EN ISO class 3M2 the measured H.E.R. is about equal to the value measured under ANSI/ASHRAE. Therefore, the calculated energy consumption for refrigeration (R.E.C.) is about 70 % higher under EN ISO than the C.E.C. value calculated under ASHRAE. The direct energy consumption (lights, fans, etc.) measured under EN ISO however is generally lower than the value calculated under ANSI/ASHRAE, as EN ISO uses only 12 hours of lighting per day as opposed to 24 under ANSI/ASHRAE, but the direct energy consumptions constitutes only a small part of the total energy consumption for multi-deck remote cabinets (on average 6% for 237 cabinets in the Eurovent database).

Table 33. Estimated REC or CEC values (kWh/day) for identical remote RDC appliances tested at different evaporating temperatures T_0 according to ANSI/AHRI 1201 and EN-ISO 23953, at an average cooling capacity or heat extraction rate of 1 kW over 24 hours

	CEC (ANSI/AHRI 1201)	REC (EN ISO 23953)	Difference
T_0 = 0 °C	5.26	9.04	+72%
T_0 = −10 °C	7.18	12.07	+68%
T_0 = −20 °C	9.52	15.34	+61%
T_0 = −30 °C	12.24	18.87	+54%

Taking the above factors into consideration, the TEC value recorded under EN ISO is 50% - 65% higher than the value under ASHRAE for identical remote multi-deck cabinets with EN ISO classification 3M2. LT cabinets typically operate at evaporating temperatures of around -30 ^{o}C. For open-island remote cabinets in EN ISO class 3L3 the measured H.E.R. is 7.5 % higher than the value measured under ANSI/ASHRAE (Table 30). If the conversion factors in Table 32 are also taken into account the calculated energy consumption for refrigeration (R.E.C.) is about 65 % higher under EN ISO for remote freezer island cabinets classified as 3L3 than the C.E.C. value calculated under ASHRAE.

Although the direct energy consumption (lights, fans, defrost, etc.) constitutes a larger part of the energy consumption (22% on average for 42 remote LT island cabinets in the Eurovent database), the value measured under EN ISO should be about equal to the value calculated under ANSI/ASHRAE. The effect of the 65% higher REC value would therefore result in a 44 % higher TEC value under EN ISO than under the ASHRAE (3L3 classification). When using the average TEC/TDA values defined by Eurovent for 3L3, 3L2 and 3L1 cabinets, we can further deduce that for 3L2 cabinets the EN ISO TEC value would be 55% higher than the ANSI/ASHRAE TEC value and for 3L1 cabinets 66% higher. Thus to summarise the above findings, the TEC value measured under EN ISO will be from 44% (at 3L3) to 66% (at 3L1) higher than the value under ANSI/ASHRAE for identical remote open freezer island cabinets, Table 34. Adjusted (i.e. using the conversion factors in Table 33) comparisons of market average TEC/TDA values are given in Table 35.

Table 34. Estimated relative total energy consumption (TEC) for refrigerated display cabinets (as defined by EN ISO 23953), when tested according to the ASHRAE 72 – ANSI/AHRI 1200 and to the EN ISO 23953 standards*.

Cabinet type	EN ISO Classification	Compressor	Total energy consumption	
			ASHRAE 72 – ANSI/AHRI 1200	EN ISO 23953
MT open multi-deck	3M2	Integral	100%	95%
		Remote	100%	150–165%
LT open island	3L3	Integral	100%	106%
		Remote	100%	144%
	3L2	Remote	100%	155%
	3L1	Remote	100 %	166 %

Abbreviations: LT = low temperature; MT = medium temperature

*Note, the TEC values measured under the ASHRAE 72 – ANSI/AHRI 1200 values are the reference values and set at 100%.

Table 35. Average total energy consumption/total display area (TEC/TDA) for EN ISO (RVC2, 3M2) and American remote medium-temperature multi-deck cabinets when converted to be on a comparable basis[a]

Dataset	No. of models	TEC/TDA (kWh/day.m^2)		Comparison of adjusted values to California average
		Average	Converted to ASHRAE-ANSI/AHRI	
California database (2013)	140	7.38	7.38	100%
Eurovent database (March 2013)	237	7.46	4.74	64%
Eurovent average TEC/TDA – 40%	Unknown	7.38	4.69	63%
Australia MEPS registration database. RS2 unlit	209	10.30	6.51	88%
Australia energy rating database 2013	22	8.22	5.22	71%
South Africa internet data 2013	48	9.88	6.27	85%

[a] Corrections applied according to the results of and approach used in Table

There is a difference between the American and European/Australian multi-deck remote cabinets. This is probably due to the fact that for European/Australian cabinets, testing with night blinds is commonplace and leads to a 21% - 25% reduction in TEC[13]. In the US, open-front multi-deck refrigerated display cases are generally not tested with night covers in place and most supermarkets do not use night covers on open cases[14].

Integral MT open multi-deck cabinets

Energy performance results for integral open multi-deck MT cabinets, including those adjusted for differences in the test procedure, are reported in Table 36. There are only small differences between the European and Australian data sets, but the difference with the US data is remarkable – especially as contrary to the case with the remote cabinets, the American cabinets are far more efficient than the European and Australian cabinets.

Table 36. Average total energy consumption/total display area (TEC/TDA) for EN ISO and American integral medium-temperature multi-deck cabinets (3M2)*.

Data set	No. of models	TEC/TDA (kWh/day.m^2)		Comparison of adjusted values to California average
		Average	Converted to ASHRAE-ANSI/AHRI	
California database 2013	10	9.03	9.03	100%
Phoenix retail data (UK, 2010)	16	16.89	17.78	197%
Eurovent average TEC/TDA	Unknown	15.10	15.90	176%
Australia MEPS register. IVC2 M2	± 100	15.67	16.49	183%
Australia energy rating 2013	18	15.89	16.73	185%

[a] Corrections applied according to the results of and approach used in Table

[13] Empirical evidence from European test results
[14] Email communication from Van Baxter, ORNL, USA

It should be noted however that the California database contains only 10 entries for this category, representing 3 different cabinets (with extra entries for different lengths), and thus the reported results may not be statistically representative of the US market as a whole.

Remote LT open-island cabinets

Energy performance results for remote LT open-island cabinets, including those adjusted for differences in the test procedure applied, are reported in Table 37.

Table 37. Average total energy consumption/total display area (TEC/TDA) for EN ISO (RHF3 and RHF4) and American remote low-temperature open island cabinets*.

Data set	No. of models	TEC/TDA (kWh/day.m^2) Average	TEC/TDA (kWh/day.m^2) Converted to ASHRAE-ANSI/AHRI	Comparison of adjusted values to California average
California database (2013)	6	7.58	7.58	100%
Eurovent (March 2013)	26	10.73	7.45	98%
Eurovent average TEC/TDA – 40 %	Unknown	9.00	5.42	72%
Australia MEPS register. RS13/14	71	14.27	8.60	113%
Australia energy rating 2013	None	-	-	-
South Africa internet data	12	16.51	10.48	138%

[a] Corrections applied according to the results of and approach used in Table

Integral LT open-island cabinets

Energy performance results for integral LT open-island cabinets, including those adjusted for differences in test procedure, are reported in Table 38. Since there are no data in the California database, no comparison to California average is presented.

Table 38. Average total energy consumption/total display area (TEC/TDA) for EN ISO (IHF3 and IHF4) and American integral (plug-in) low-temperature open-island cabinets*.

Data set	No. of models	TEC/TDA (kWh/day.m^2) Average	TEC/TDA (kWh/day.m^2) Converted to ASHRAE-ANSI/AHRI	Comparison of adjusted values to California average
California database (2013)	None	-	-	-
Eurovent (March 2013)	None	-	-	-
Eurovent average TEC/TDA (3L3)	Unknown	18.90	17.80	-
Australia MEPS register IHF4	71	20.00	18.87	-
Australia energy rating 2013	40	22.53	21.25	-

[a] Corrections applied according to the results of and approach used in Table

A comparison of the US, European and Australian commercial refrigeration equipment databases shows that for integral (plug-in) cabinets many manufacturers operate across the regions, which tends to unify the stocks in terms of performance. For remote cabinets however, there are manufacturers supplying both the EU and Australian markets, but there is little cross-over in supply between these regions and the USA. As to regions outside the USA, Europe and Australia, we have to consider that manufacturers in the major economies apply energy efficient parts for the home-market, but for "export" markets may apply less efficient – cheaper – parts (e.g. Hussmann identifies commercial refrigeration equipment with both export grade and with energy efficient evaporator fans[15]).

The impact of applying all the above correction factors (as derived in Table 34) on the data presented in Table 19 is shown in Table 39 for the case where all energy consumption values are corrected to be reported under EN-ISO test conditions. Note, in practice this only requires the USTSD and California data to be adjusted.

Table 39. Average total energy consumption/total display area (kWh/m2) for remote and integral display cabinets in various economies after adjusting all data to be reported under EN-ISO test conditions

Type EN-ISO	Australia		California		China		EU (Eurovent)		Japan		RSA		USA TSD
	kWh/m2	No.	kWh/m2	No.	kWh/m2	No.	kWh/m2	No.	kWh/m2	No.	kWh/m2	No.	kWh/m2
RVC2	10.3	209	11.1	139	28.8	4	7.5	237	5.7	45	9.9	48	14.0
RHF4	14.3	71	12.6	6	10.8	8	10.7	26	12.9	20	16.5	12	12.8
IVC4	10.1	517	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	2.7
IVC2	14.8	211	8.6	10	NA	NA	15.1	NA	NA	NA	15.6	2	20.4
IHF4	18.9	38	NA	NA	NA	NA	20	NA	NA	NA	NA	NA	28.5
IHF6	6.6	213	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	6.4

Sources: Australia energy rating database (2013), California CEC database (2013) adjusted to EN ISO, China energy label database (2013), EU Eurovent database (March 2013), Japan (Fukushima catalogue, 2013), South Africa (manufacturer internet data 2013), USA – USDOE Technical Support Document spreadsheets adjusted to EN-ISO.

Conversion between NOM-022-ENER/SCFI and ISO EN 23953 or ASHRAE 72

Table 40 shows the results of a similar analytical exercise from comparing results measured under the ISO EN or ANSI/ASHRAE standards with the Mexican NOM-022-ENER/SCFI standard. Thus the application of the conversion factors in Table 34 or Table 40 will allow energy performance conversions to be made for all the economies considered in this study as they all use EN ISO, ANSI/ASHRAE or the Mexican test procedure.

Table 40. Energy consumption for cabinet types, estimated under the NOM-022-ENER/SCFI, ASHRAE 72 – ANSI/AHRI 1200 and EN ISO 23953 standards for identical cabinets (without night covers)*.

Cabinet type (integral only)	Classification			
	EN ISO	NOM-022-ENER/SCFI	ASHRAE 72 – ANSI/AHRI 1200	EN ISO 23953
MT forced circulation	3M2	100%	63%	66%
MT cold plate	3H	100%	69%	64%
MT glass door	3M2	100%	–	–
LT open island	3L1	100%	76%	78%
LT ice cream	3L1	100%	105%	78%
LT glass door	3L1	100%	–	–

Abbreviations: LT = low temperature; MT = medium temperature.*Values evaluated under NOM-022-ENER/SCFI have been designated as reference (100%).

[15] Hussmann Data sheet D5X-E, September 2012.

2.7 Higher energy efficiency design options and potential efficiency improvement cost-benefits

A basic understanding of the physics of refrigerated display cabinets and vending machines is very helpful when trying to identify options for increasing energy efficiency of commercial refrigerating equipment, for reach-in coolers as well as vending machines.

Reach-in coolers - background.

The total energy consumption (TEC) for remote reach-in-coolers consists of direct energy consumption (DEC) for electrical components such as fans and lighting and the calculated consumption for the production of "cold" used by the cabinet (refrigeration energy consumption, REC), Table 41. Reported energy savings are sometimes expressed in terms of savings in the REC, and sometimes as savings in the TEC, which can lead to confusion.

Table 41. Average contributions to total energy consumption from refrigeration and direct sources (assessed from market data) for open chilled multi-deck cabinets (RVC2) and open freezer islands (RHF4)

Type	Refrigeration energy consumption	Direct energy consumption	Total energy consumption
RVC2	± 85%	± 15%	100%
RHF4	± 60%	± 40%	100%

The demand for coolth (and its associated REC) is driven by the following heat gains into the cabinet:

- infiltration of warm air
- conduction through the insulation
- dissipated heat inside the cabinet (from fans, lights, window heaters and defrosting)
- radiation

Table 42, gives an estimate of the importance of these different elements in the total cooling energy required for open chilled multi-deck cabinets (RVC2) and open freezer islands (RHF4). The elements that are most responsible for cooling energy demand are also those where potential energy saving options will be most effective. Thus it is clear that improving insulation is not a very effective energy saving option in open reach-in coolers (and subsequently vacuum insulation is not applied in the most efficient cabinets found on the market) whereas it is a viable option for closed cabinets.

Table 42. Heat load distribution for open chilled multi-deck cabinets (RVC2) and open freezer islands (RHF4)*

Type	Infiltration	Conduction	Dissipation	Radiation	Heat extraction rate
RVC2	± 78%	± 3%	± 10%	± 9%	100%
RHF4	± 24%	± 17%	± 16%	± 43%	100%

*(from: Carbon Trust refrigeration roadmap).

The evaporation temperature is another important driver of cooling energy demand and is determined by the size (capacity) of the evaporator (coil). In practical installations, the efficiency of the condensing unit is also important, however this factor is normalised under the measurement and rating standards and so does not affect the relative results they produce.

When considering the impact of design options that produce energy savings in the direct electrical energy consumption (DEC), it should be kept in mind that the impact of these savings on the overall

TEC is larger than just the sum of their direct savings. This is because the heat from electrical components is mostly dissipated inside the cabinet and thus additional cooling capacity and energy is needed to extract it. Thus, when the electrical load is reduced, the required cooling capacity (and thus the REC) is also reduced, giving an additional benefit.

Reach-in coolers – options for increasing energy efficiency.

The most commonly encountered methods in practice of increasing energy efficiency of open reach-in coolers are glass doors, night covers, high efficiency fans, LED lighting and (in positive temperature cabinets) natural defrost or (in low, i.e. negative, temperature cabinets) defrost ending thermostats.

The EU Lot 12 Ecodesign preparatory study[16] presents energy saving options for remote open multi-deck cabinets and open freezer islands with associated simple payback times (Table 43 and Table 44). It should be noted that the option "liquid suction heat exchanger" is only advantageous with certain refrigerants.

Table 43. EU Ecodesign Lot 12 energy-saving options for remote open multi-deck chiller cabinets (RVC2). Cost estimates relate to a cabinet providing 7.0 m² total display area[1]

	Improvement option	TEC savings compared to base case RCV2	Increase of product cost compared to base case RCV2 (€)	Payback time (year)
Option 1	Night curtain	26.0 %	200	0.28
Option 2	Optimisation of the air curtain (double air curtain)	10.0 %	140	0.51
Option 3	ECM evaporator fans	8.2 %	135	0.60
Option 4	Liquid suction heat exchanger (LSHE)	2.5 %	60	0.88
Option 5	Addition of a glass door (alternative to night curtain)	52.0 %	1750	1.33

Abbreviations: ECM = Electronically commutated motor; TEC = total energy consumption.

[1] Note, savings and payback times are all compared to a base case model and are not cumulative with successive design options

Table 44. EU Ecodesign Lot 12 energy-saving options for remote open-island freezer cabinets (RHF4). Cost estimates relate to a cabinet providing 7.0 m² total display area[1]

	Improvement Option	TEC savings compared to base case RHF4	Increase of product cost compared to base case RHF4	Payback time (year)
Option 1	Night curtain	18.0 %	400	0.77
Option 2	Liquid Suction Heat Exchanger (LSHE)	2.0 %	50	0.87
Option 3	Anti-sweat heaters control	6.0 %	165	0.95
Option 4	ECM evaporator fans	3.5 %	225	2.23
Option 5	Addition of a glass lid (alternative to night curtain)	36.5 %	2250	2.40

[16] Preparatory studies for Ecodesign requirements of EUP's lot 12: commercial refrigerators and freezers http://www.ecofreezercom.org/

Abbreviations: ECM = Electronically commutated motor; TEC = total energy consumption.

[1] Note, savings and payback times are all compared to a base case model and are not cumulative with successive design options

Similar options are given in the UK Carbon trust Refrigeration roadmap[17], which cover both the cabinets and the condensing units (in the case of remote refrigeration systems), Table 45.

Some of the options mentioned are still in a development phase. Anti-frost evaporators are one such option – where the term itself does not implicate that no frost forms on the evaporator, but rather that when defrosted, water droplets do not cling to the (hydrophobic) evaporator surface.

Other potential energy savings options have some practical disadvantages. Strip curtains are prone to wear, which decreases visibility, and condensation often occurs on the curtains, which may impair hygiene. Tangential fans produce a small energy saving benefit, but are more difficult to clean than axial fans and thus may lead to unhygienic situations.

The application of glass doors in particular may have an effect on the supermarket operations. Cabinets with glass doors are less easy to refill than open cabinets and also the effort needed in cleaning the cabinets is larger with glass doors than with open cabinets. These costs (to the supermarket operator) are often not considered in the payback time calculations. The belief that glass doors would adversely affect sales, however, has never been proven in practice; whereas the indoor thermal comfort of shoppers increases when glass doors are applied.

[17] Carbon Trust Refrigeration Roadmap, UK, March 2010

Table 45. Savings options for refrigerated display cabinets reported in the UK Carbon Trust refrigeration roadmap

Option	Application	RVC2/RHF4	Payback (years)
Air curtain optimisation	MT cabinets	RVC2	1.1
Anti-fogging glass	LT glass-door cabinets	–	0.4
Anti-frost evaporators	LT cabinets	RHF4	2.6
Anti-sweat heater control	LT glass-door cabinets	–	0.6
Air-flow optimisation back panel	MT cabinets	RVC2	1.4
Efficient fluorescent lighting	All cabinet lights	RVC2	1.0
Centrifugal fans	All cabinet fans	RVC2/RHF4	1.4
Covers	Island cabinets	RHF4	0.3
Strip curtains	MT vertical cabinets	RVC2	1.2
Defrost controls	LT cabinets	RHF4	1.5
Glass doors	MT vertical cabinets	RVC2	3.7
Dual/triple air curtains	MT cabinets	RVC2	3.1
DC fans (ECM or PSC)	All cabinet fans	RVC2/RHF4	0.1
Micro-channel evaporators	MT cabinets	RVC2	4.2
LED lighting	All cabinet lights	RVC2	5.0
Night blinds	Vertical cabinets	RVC2	1.5
Occupancy sensors for lights	All cabinet lights	RVC2	2.3
Occupancy sensors doors	LT glass-door cabinets	–	0.6
Tangential fans	All cabinet fans	RVC2/RHF4	4.6
Variable speed drives	Integral cabinets	–	4.6
Reduce off-cycle losses	Integral cabinets	–	0.1
Hydrocarbon refrigerant	Integral cabinets	–	1.5

Abbreviations: ECM = Electronically commutated motor; LT = low temperature; MT = medium temperature; PSC = Permanent split capacitor.

The USDOE technical support document (TSD)[18] on energy efficiency standards for commercial and industrial equipment - provides an engineering analysis in chapter 5 (of the TSD), in which a number of design options to increase the energy efficiency of commercial refrigeration equipment are considered, Table 46.

[18] Technical support document energy efficiency standards for commercial and industrial equipment – commercial ice cream freezers, self-contained commercial refrigerators, freezers, and refrigerator-freezers without doors, and remote condensing commercial refrigerators, freezers, and refrigerator-freezers. Chapter 5: engineering analysis & appendix B. US Department of Energy, August 2008.
http://www.regulations.gov/#!documentDetail;D=EERE-2006-STD-0126-0058

Table 46. The USDOE CRE higher efficiency design options*

Design options	Analysed
Higher-efficiency lighting	Yes
Higher-efficiency lighting ballasts	Yes
Remote lighting ballast location	No
Higher-efficiency evaporator fan motors	Yes
Evaporator fan motor controllers	No
Higher-efficiency evaporator fan blades	No
Increased evaporator surface area	Yes
Low pressure differential evaporators	No
Insulation increases or improvements	No
Defrost mechanism	No
Defrost-cycle control	No
Higher-efficiency compressors (self-contained equipment only)	Yes
Increased condenser surface area (self-contained equipment only)	Yes
Higher-efficiency condenser fan motors (self-contained equipment only)	Yes
Higher-efficiency condenser fan blades (self-contained equipment only)	No

*Source: Technical support document energy efficiency standards for commercial and industrial equipment – commercial ice cream freezers, self-contained commercial refrigerators, freezers, and refrigerator-freezers without doors, and remote condensing commercial refrigerators, freezers, and refrigerator-freezers. Chapter 5: engineering analysis & appendix B. US Department of Energy, August 2008.

The options are extensively documented, both in terms of their influence on energy consumption and their cost. In the analysis presented in the TSD these were applied successively to base case equipment (defined for 15 commercial refrigeration equipment classes) to arrive at aggregate cost – efficiency curves for each equipment type. Under this methodology, the energy saving impact of each successive design option takes into account the energy efficiency improvement already achieved by the options previously applied. Detailed results of cost-efficiency curves and the underlying design options applied are provided in Appendix B of the TSD and summary findings for two product classes are shown in Tables 47 and 48.

Table 47. Cost-efficiency table from DOE Technical Support Document for remote vertical (multi-deck) open cooling refrigerated display cabinets (product class RVC2)

Design Option Level	TDA-Normalized Daily Energy Consumption [kWh/day/ft^2]	TDA-Normalized Manufacturer Selling Price [$/ft^2]	Design Option Change Above the Baseline
AD1	1.09	79.12	-
AD2	1.04	79.76	AD1 + PSC Evaporator Fan Motors
AD3	0.98	81.30	AD2 + ECM Evaporator Fan Motors
AD4	0.95	82.90	AD3 + "Super" T8 Electronic Lighting
AD5	0.90	87.59	AD4 + High-Performance Evaporator Coil
AD6	0.89	88.58	AD5 + Additional ½" Insulation
AD7	0.76	129.36	AD6 + LED Lighting

Abbreviation: TDA = total display area, AD1 = base case model

Table 48. Cost-efficiency table from DOE Technical Support Document for remote horizontal open freezer (island) cabinet (product class RHF4)

Design Option Level	TDA-Normalized Daily Energy Consumption [kWh/day/ft²]	TDA-Normalized Manufacturer Selling Price [$/ft²]	Design Option Change Above the Baseline
AD1	0.83	93.63	-
AD2	0.81	94.12	AD1 + PSC Evaporator Fan Motors
AD3	0.77	95.31	AD2 + ECM Evaporator Fan Motors
AD4	0.73	97.40	AD3 + High-Performance Evaporator Coil
AD5	0.72	98.56	AD4 + Additional ½" Insulation

Abbreviation: TDA = total display area, AD1 = base case model.

It is remarkable that the DOE TSD rules out consideration of glass doors and night blinds as energy saving options, and also rules out consideration of any potential improvements to the efficiency of air curtains used in open cabinets. Furthermore, options that save energy in the practical retail environment, but not in the laboratory environment, such as anti-sweat heater control and anti-fogging glass, are not considered in the DOE-TSD.

In an earlier US study, performed by Arthur D. Little[19], similar improvement options are given as those mentioned in the DOE TSD. PSC and ECM fan motors are quoted with payback times of 0.8 to 1.9 years (depending on energy costs, which vary by US geographical location). High efficiency lighting was shown to be an economical option, even with 1996 technology. Insulation improvements are dismissed as having a too long a payback time (21 – 40 years). Anti-sweat heater controls are favoured, however, with payback times of between 1.3 and 1.8 years. Improvements in evaporator coil performance are mentioned in this study, but the authors estimate that the associated increase in fan power will mitigate against an overall reduction in energy consumption, based on an analysis with conventional evaporator fans. This option is therefore not included in the economic analysis.

The overall view from the Eco design, UK Carbon Trust road map, Arthur D. Little and US TSD studies indicates that the following energy saving options are available and economically viable to improve the energy efficiency of commercial refrigeration equipment:

- night covers
- glass doors
- higher efficiency lighting or LED lighting
- high efficiency fans
- higher efficiency evaporator coils
- anti-sweat heaters with anti-fogging heater control
- improved insulation

2.8 Life cycle cost energy engineering analysis for reach-in coolers

Life Cycle Cost Curves (LCCs) give an insight into the optimum energy performance level from a total cost of ownership perspective. The LCC depends on locally varying circumstances such as energy prices and (ambient) temperature levels, which are liable to vary systematically between the

[19] *Energy savings potential for commercial refrigeration equipment*, Arthur D. Little Inc. for DOE, June 1996, reference 46230 - 00

different economies in this study. These local differences in LCCs may help to explain some of the variation in product energy efficiency observed between the different economies.

An engineering analysis on reach-in coolers was performed by the US DOE in 2008, and is documented in the DOE technical support document (chapter 5). The spread-sheets that have been developed by DOE in the framework of that engineering analysis have been made available to the public at http://www.regulations.gov (document EERE-2006-STD-0126-0080). The techno-economic analyses in these USDOE spread-sheets, have been revised (with respect to a number of issues) and rerun for the current analysis. These revised engineering analyses have been done for the six most prevalent reach-in cooler equipment categories for each economy of interest to the current study.

The first four equipment categories for which these techno-economic engineering analyses are conducted are the same as those investigated earlier in this study during the comparison of reach-in cooler energy consumption figures across economies, namely:

- VOP-RC-M Vertical Open (multi-deck) medium temperature, remote (EN-ISO: RVC2)
- VOP-SC-M Vertical Open (multi-deck) medium temperature, integral (EN-ISO: IVC2)
- HZO-RC-L Horizontal open (island/chest) low temperature, remote (EN-ISO: RHF4)
- HZO-SC-L Horizontal open (island/chest) low temperature, integral (EN-ISO: IHF4)

The other two categories addressed are the same as those considered in the IEA 4E commercial refrigeration equipment benchmarking studies, namely:

- HCT-SC-I Horizontal ice cream freezer with transparent cover, integral (EN-ISO: IHF6)
- VCT-SC-M Vertical glass door medium temperature (bottle cooler), integral (EN-SO: IVC4)

It should be noted that the integral vertical glass door cabinet (the last category in the list above) is only analysed in its low temperature (ice cream display) configuration in the original USDOE engineering analysis thus the spread-sheet has been modified in the current analysis to also enable medium temperature products to be studied.

The same material and incremental component costs are assumed in the present study as for the original US DOE analysis, except in the case of LED lighting, where updated (2013) values have been used. This is because while other component/material costs will be little changed from the 2008 levels the LED performance and cost has changed radically. The costs for installation, maintenance and repair used in the present analysis are also copied from the original 2008 values. By contrast, different average energy prices and (ambient) temperature levels are assumed for each economy. In order to be consistent with other recent SEAD studies for air conditioners and refrigerators the electricity tariff values applied are those that were reported for 2009. The only exceptions are for China and India, where we used alternative (more reliable) electricity price data from sources on the internet, Table 49.

Table 49. Electricity price data (2009) used in the revised engineering analysis and for constructing LCC curves.[1]

	Economy								
	Australia	Brazil	China	EU	India	Japan	Mexico	RSA	USA
Price (US$/kWh)	0.102	0.180	0.091	0.177	0.056	0.167	0.111	0.066	0.100

[1]From Cooling the Planet: Opportunities for Deployment of Super-Efficient Room Air Conditioners http://www.superefficient.org/en/Resources/~/media/Files/SEAD%20Technical%20Analysis%20Reports/SEAD%20Room%20AC%20Analysis/Final%20SEAD%20Room%20AC%20Report.pdf

The original DOE engineering analysis was done at the standard condition of 75 ^{o}F and 55 % relative humidity and assumed that lighting operated for 24 hours per day. This condition reflects the ASHRAE measurement standard. In addition to doing the revised techno-economic energy engineering analyses at this condition, two extra conditions are added as follows:

- a "European" condition, reflecting the EN-ISO test standard with ambient test conditions of 25 ^{o}C (77 ^{o}F) and 60% relative humidity and with 12 hours of lighting per day
- a "Store" condition reflecting typical "in store" conditions, with an ambient temperature of 20 ^{o}C (68 ^{o}F) at 55 % relative humidity and 12 hours of lighting per day

These extra conditions are included to enable results to be compared under EN-ISO test conditions and under more realistic in situ conditions, Table 50.

Table 50. Conditions used in the revised engineering analysis*.

Condition	Ambient Temperature	Rel. humidity	Case Lighting
DOE (ASHRAE)	75^{0}F (23,9 ^{o}C)	55 %	24 hr. / 24 hr.
EU (EN-ISO)	77^{0}F (25 ^{o}C)	60 %	12 hr. / 24 hr.
Store	68^{0}F (20 ^{o}C)	55 %	12 hr. / 24 hr.

* The DOE condition was used in the original DOE analysis.

The energy saving design options included in the revised engineering analysis are the same as in the original USDOE engineering analysis, except in the case of the multi-deck cabinets (both remote and integral types). In the case of the multi-deck cabinets, the energy savings options of night covers and single pane glass doors, which are quite applied in Europe, have both been considered.

Specifically the use of motorised night covers reduces air infiltration during the night time. Based on current knowledge it is assumed that the use of night covers reduces infiltration by some 50 % during this period, leading to an overall energy saving of 20 – 25 %. The costs assumed for motorised night covers are assumed to be €124 per meter (ECN study, the Netherlands, 2012).

Similarly, the use of single pane glass doors reduces air infiltration during both the night time and daytime hours, and their use is assumed to reduce infiltration by 50 %. No additional anti-sweat heating is necessary when applying these doors to medium temperature (chilled) cabinets. The costs for single pane glass doors are assumed to be € 766 per meter (ECN study, the Netherlands, 2012).

Chest freezers are the first group investigated among the six reach-in cooler equipment classes for which the revised engineering analyses are performed because they do not contain lighting and hence the influence of ambient temperature and energy prices is illustrated, without the additional impact of different activation times for cabinet lighting. Three categories of chest freezers are investigated:

- open horizontal freezer island, remote (RHF4)
- open horizontal freezer island, integral (IHF4)
- glass lid (ice cream) chest freezer, integral (IHF6)

Open horizontal freezer island, Remote (RHF4)

The Baseline open horizontal freezer island (RHF4) has a TDA of 4.27 m^2 and an energy consumption of 38.4 kWh/day at ASHRAE test standard conditions (75 ^{o}F, 55 % RH) or 8.99 kWh/m^2/day.

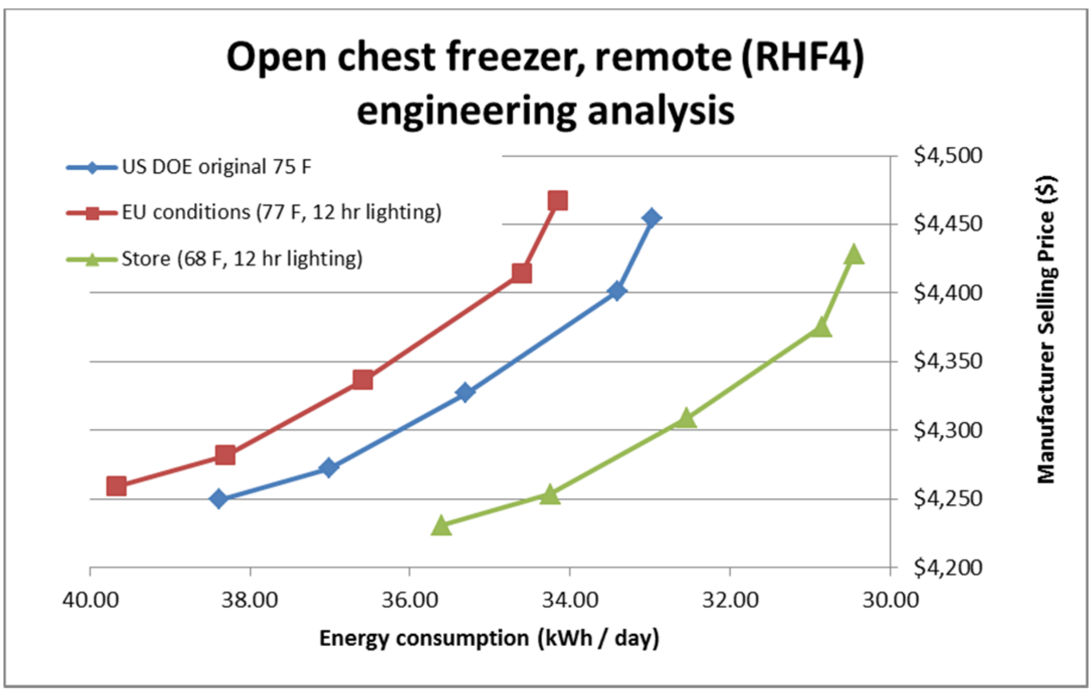
Figure 11. Example of an open horizontal freezer island, class RHF4

In the techno-economic engineering analysis, four design options are applied consecutively:

- permanent split capacitor evaporator fan – motor
- brushless DC evaporator fan motor
- enhanced-UA[20] evaporator coil
- additional 1/2" of insulation

The techno-economic engineering analysis results show the influence of the differences in ambient conditions on the energy consumption, Figure 12. The price levels are only marginally influenced by the different (design) conditions. There is no cabinet lighting.

Figure 12. Estimated sales price (US$) as a function of energy consumption for an open chest freezer (class RHF4, TDA=4.27 m2) under typical in-store conditions, EN-ISO test conditions and US test conditions.

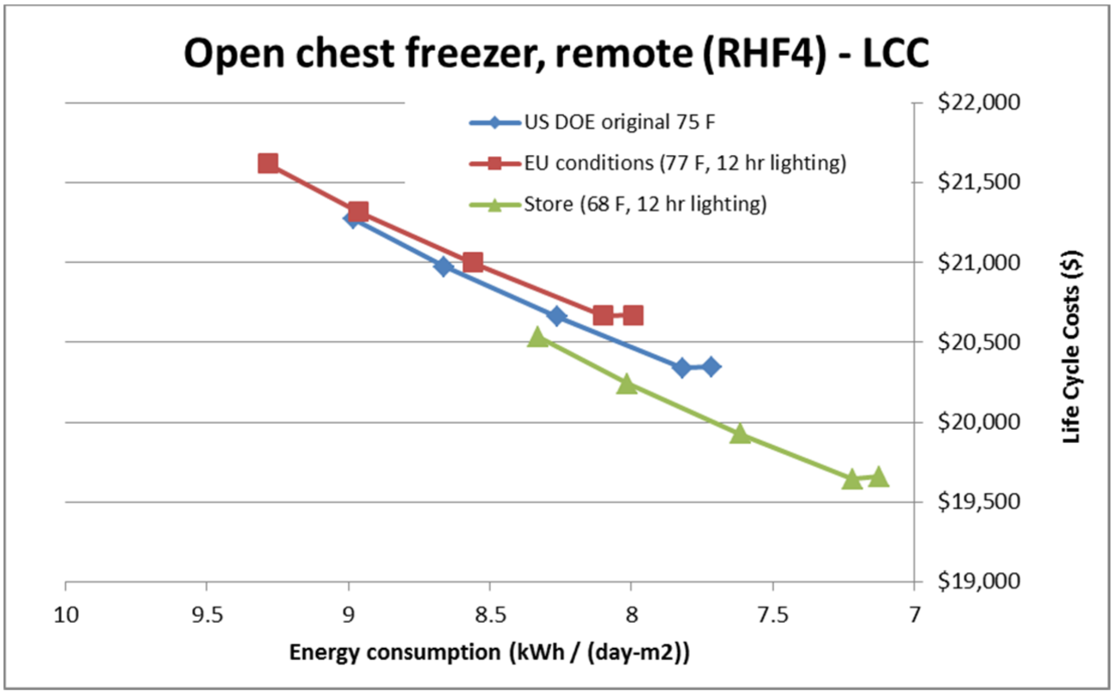


[20] U-value times area = conductivity

The condition leading to the highest energy consumption is the International EN-ISO test standard condition of 25 ^{o}C and 60% relative humidity. The "in store" condition of 20 ^{o}C (68 ^{o}F and 55% relative humidity) leads to the lowest energy consumption (11% lower than at the EN-ISO condition).

The LCC curves for the different conditions again show the impact on energy consumption of differences in the various ambient conditions, Figure 13. The LCC minimum remains at the same design option level (option 3, enhanced evaporator coil) for all three ambient conditions. At this level the TEC/TDA value is 7.82 kWh/m^2/day, under ASHRAE test conditions. This is close to the average of the California database of 7.58 kWh/m^2/day (data added in 2012), especially when updated to consider that historically there has been an average efficiency improvement of some 2.5 % per year.

Figure 13. Estimated life cycle costs (US$) as a function of energy consumption for an open chest freezer (class RHF4, TDA=4.27 m2) under typical in-store conditions, EN-ISO test conditions and US test conditions.



Figures 12 and 13 show that an increase in manufacturer selling price of $144 (from $4231 to $4375) would yield annual energy savings of $127 under store conditions, and life cycle savings (discounted at 0% real discount rate over 7 years) of $892.

The LCC curves shown in Figure 13 are determined at the 2009 US average energy price level of 0.10 $/kWh. Information on LCC values at other energy costs, as seen in the various economic regions of interest to this study, is given in Appendix A. From this it is seen that in regions with higher energy prices, the LCC minimum occurs at one design option "up" from the US level, at almost the same TEC/TDA value of 7.71 kWh/m^2/day (0.1 kWh/m^2/day lower than the US value). Interestingly, this matches with the observed average TEC/TDA value of 7.45 kWh/m^2/day in the Eurovent database.

For economies with low energy prices, such as South Africa, the LCC minimum is still at the same level as that for the USA (7.82 kWh/m^2/day). Nevertheless the average TEC/TDA value of South African cabinets reported in product data available from the internet is much higher at 10.48 kWh/m^2/day, which suggests there is an economically viable energy savings potential.

Open horizontal freezer island, integral (IHF4)

The Baseline open horizontal freezer island (IHF4) has a TDA of 1.115 m^2 and an energy consumption of 38.7 kWh/day at ASHRAE test standard conditions (75 ^oF, 55 % RH) or 34.7 kWh/m^2/day.

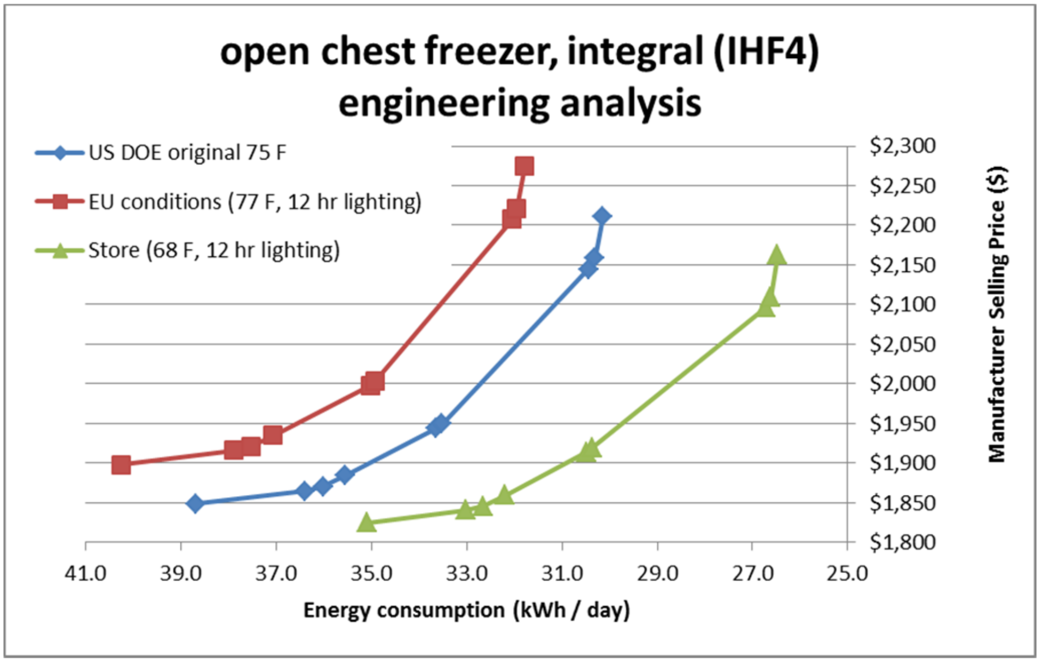
Figure 14. Example of an open horizontal freezer island, integral (class IHF4)

In the techno-economic engineering analysis, eight design options are consecutively applied (more options are available for integral cabinets than for remote cabinets, as integral cabinets contain a compressor, condenser and condenser fan whereas remote cabinets do not) as follows:

- high efficiency reciprocating compressor
- permanent split capacitor evaporator fan motor
- brushless DC evaporator fan motor
- enhanced-UA evaporator Coil
- permanent split capacity condenser fan motor
- enhanced-UA condenser coil
- brushless DC condenser fan motor
- additional 1/2" of insulation

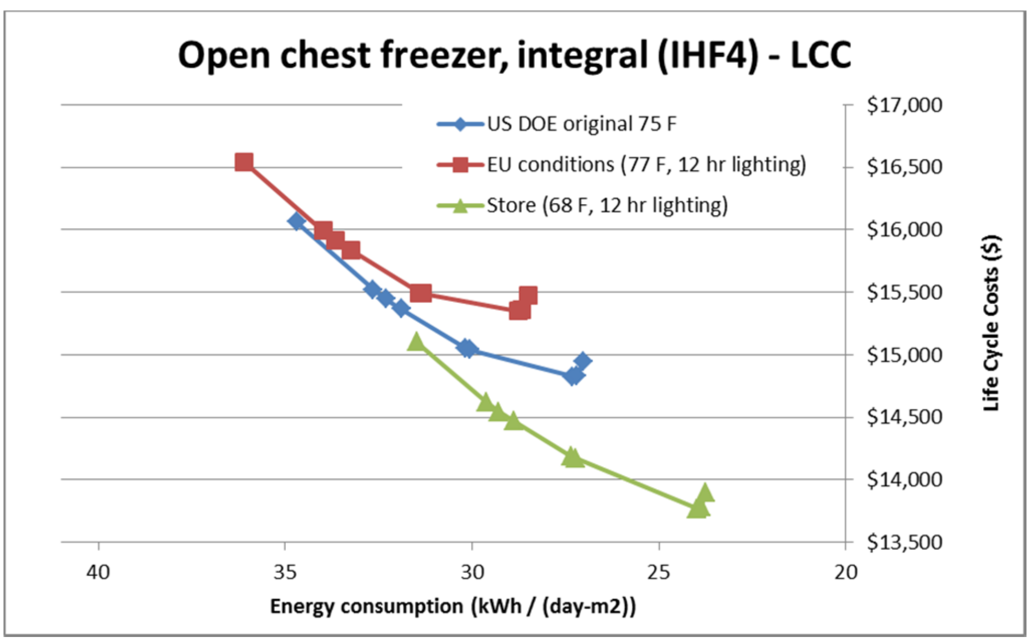
The techno-economic engineering analysis results show exactly the same tendency with ambient conditions as in the case of the remote version, with a 13% difference in energy consumption exhibited between store conditions and EN-ISO conditions, Figure 15. Again, there is no cabinet lighting.

Figure 15. Estimated sales price (US$) as a function of energy consumption of an open horizontal freezer island (class IHF4, TDA=1.115m2) under typical in-store conditions, EN ISO test conditions and US test conditions.



The LCC curves for the integral open freezer island are shown in Figure 16, where the LCC minimum is again independent of the ambient condition for the same design option (option 6, enhanced evaporator coil in all cases). The corresponding TEC/TDA value is 27.3 kWh/m^2/day under ASHRAE test conditions. Unfortunately, no US data are available for this product category.

Figure 16. Estimated life cycle costs (US$) as a function of energy consumption of an open horizontal freezer island (class IHF4. TDA=1.115m2) under typical in-store conditions, EN ISO test conditions and US test conditions.



Figures 15 and 16 show that an increase in manufacturer selling price of $236 (from $1824 to $2096) would yield annual energy savings of $100 under store conditions, and life cycle savings (discounted at 0% real discount rate over 7 years) of $698.

The LCC curves shown in Figure 16 are derived for an energy price level of $ 0.10/kWh (=US 2009 average). In Appendix A the LCC data for other energy prices and economies are presented. Here we can see that at a higher energy price, the LCC minimum is not at Option 6 but at Option 7 (at a marginally lower TEC/TDA of 27.2 kWh/m^2/day). Under low energy prices, such as for South Africa, the LCC minimum is found at design option level 5 at a TEC/TDA of 30.1 kWh/m^2/day.

It is remarkable, however, that the available market data from Australia show a significantly lower TEC/TDA value of about 20 kWh/m^2/day. No data are available for this product category in Europe but the "Average TEC/TDA" as defined by EU manufacturers is in line with the Australian data. The availability on the market of models with energy consumption 30% below the LCC minimum might signify the presence of an error in the DOE spread-sheet for self-contained (integral) horizontal freezer islands.

Horizontal ice cream freezer with glass lid, integral (IHF6)

The Baseline ice cream chest merchandizer (IHF6) has a TDA of 1.115 m^2 and an energy consumption of 38.7 kWh/day under ASHRAE standard test conditions (75 ^oF, 55 % RH).

Figure 17. Example of a horizontal ice cream freezer with glass lid, integral (class IHF6)

In the techno-economic engineering analysis, five design options have been consecutively applied:

- high efficiency reciprocating compressor
- permanent split capacitor condenser fan motor
- high-Performance glass lid
- brushless DC condenser fan motor
- additional 1/2" insulation

The techno-economic engineering analysis results show a large bandwidth in terms of energy consumption, where the lowest energy consumption value (where all energy saving design options are applied) is less than half of the baseline energy consumption, Figure 18.

The LCC curves at 2009 USA energy price levels (0.10$/kWh) for this category show a minimum at design option 3 (high performance glass lid), whereas at higher energy prices the minimum is at design option 4 (brushless DC condenser fan motor), Figure 19. The corresponding TEC/TDA values are at respectively: 7.77 kWh/m^2/day and 7.42 kWh/m^2/day. LCC data at different average energy price levels for each economy are presented in Appendix A.

Figure 18. Estimated sales price (US$) as a function of energy consumption of a horizontal ice cream freezer with glass lid, integral (class IHF6) under typical in-store conditions, EN ISO and US test conditions.

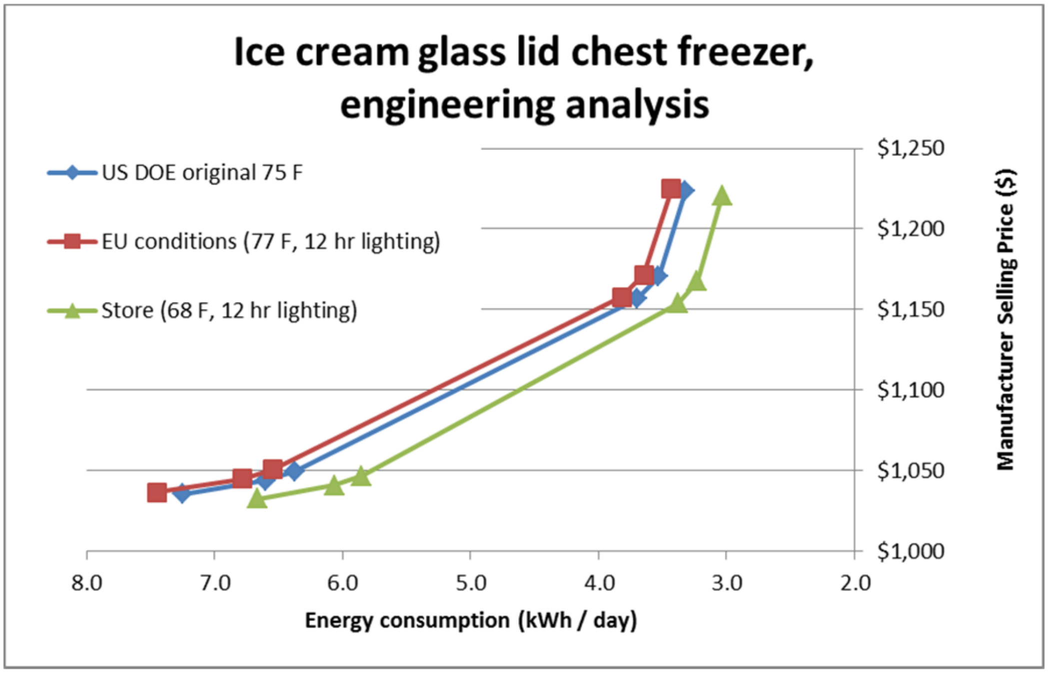
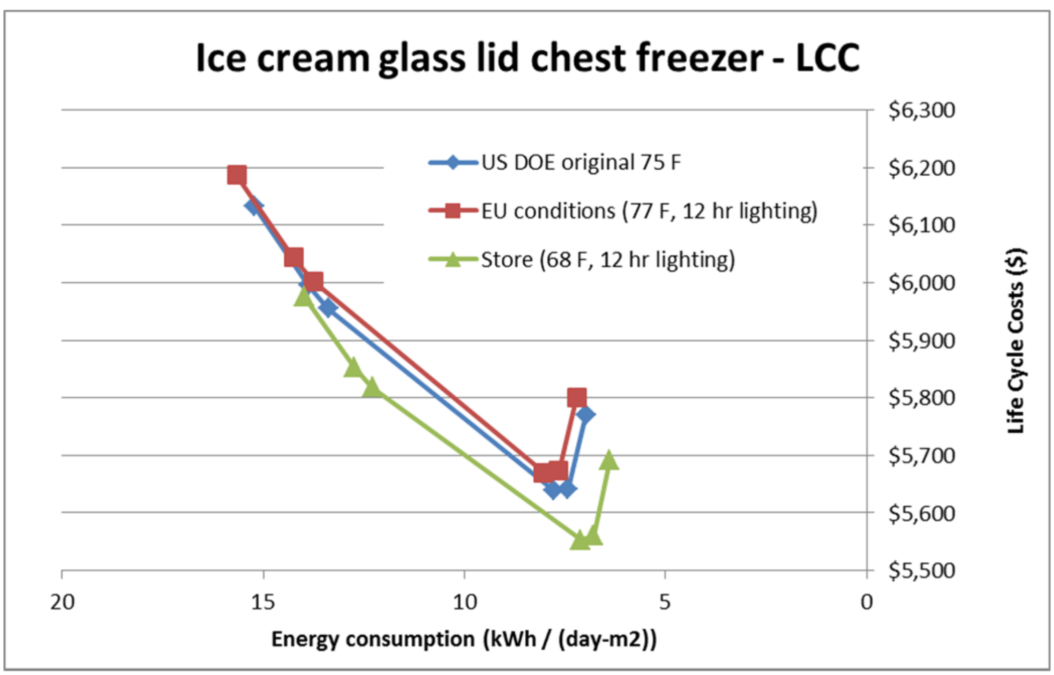


Figure 19. Estimated life cycle costs (US$) as a function of energy consumption of a horizontal ice cream freezer with glass lid, integral (class IHF6) under typical in-store conditions, EN ISO and US test conditions.



Figures 18 and 19 show that an increase in manufacturer selling price of $121 (from $1033 to $1154) would yield annual energy savings of $61 under store conditions, and life cycle savings (discounted at 0% real discount rate over 7 years) of $424.

Energy performance data on glass lid ice cream freezers are available in the IEA 4E benchmarking study on commercial refrigeration equipment. The IEA reports do not use TEC/TDA values as a comparison basis, but energy consumption per unit (storage) volume. The base case gross refrigerated volume is 10.20 ft^3, or 289 litres. At the LCC minimum, the energy consumption is 12.8 $kWh/m^3/day$.

An analysis of the US Energy Star data set, reported in the IEA 4E benchmarking study indicates an energy consumption of between 5.18 and 10.0 $kWh/m^3/day$, with an average of 7.24 $kWh/m^3/day$. These values are all considerably below the LCC minimum.

The availability on the market of models with energy consumption far below the LCC minimum might signify an error in the DOE spread-sheet for integral horizontal freezer islands (just as for open-top self-contained freezer islands).

For the California Energy Commission data set, the IEA benchmark study on USA models reports energy consumption values of between 7.17 and 106 $kWh/m^3/day$, with an average volume of 21.59 $kWh/m^3/day$. These values are much higher than in the Energy Star data set, and thus there are grounds to believe that in this case many open freezer islands were present in the IEA 4E data set (category IHF4) as opposed to glass lid ice cream freezers (category IHF6). The IEA 4E reports themselves do not distinguish between open freezer islands and glass lid freezers.

Glass door vertical, cooling (bottle cooler) Integral (IVC4)

The Baseline glass door vertical bottle cooler (IVC4) has a TDA of 2.415 m^2 and an energy consumption of 38.12 kWh/day at ASHRAE test standard conditions (75 ^oF, 55 % RH) or 15.78 $kWh/m^2/day$. The volume is 48 ft3 or 1.36 m^3, so energy consumption is 28.0 $kWh/m^3/day$.

Figure 20. Example of a glass door vertical, cooling (bottle cooler) integral unit (class IVC4)

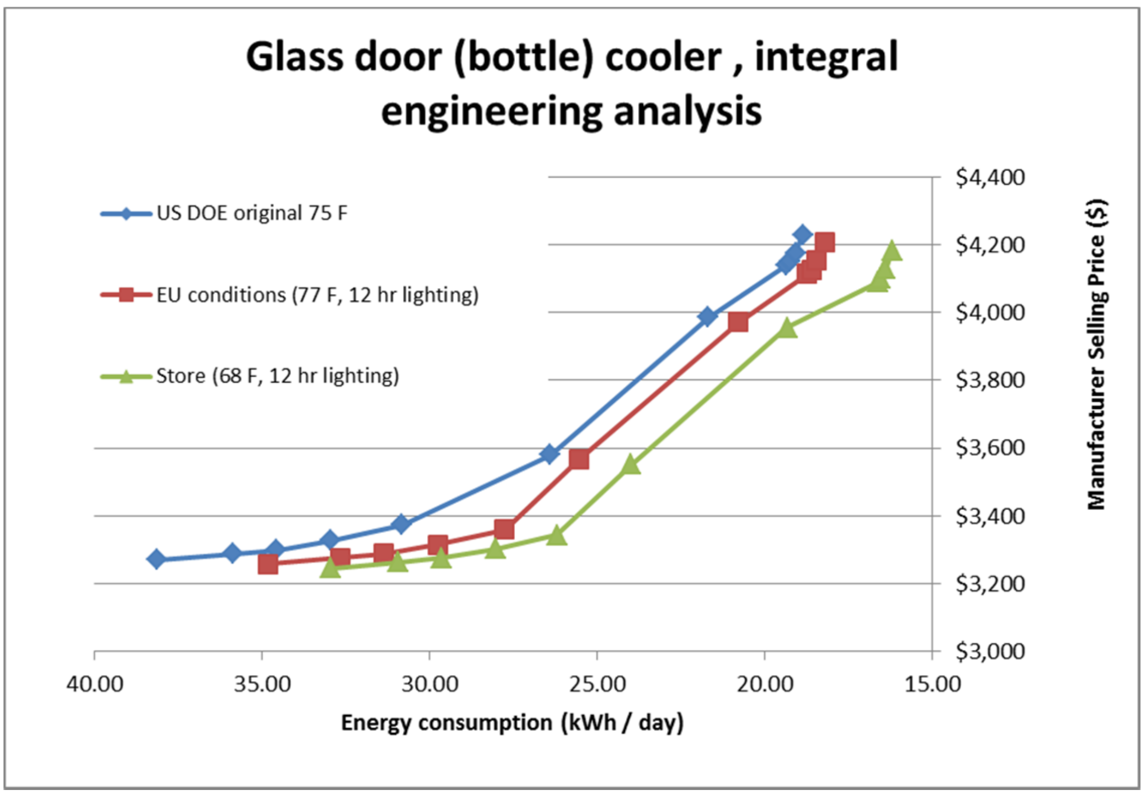
This equipment category was not studied in the original US DOE energy engineering analysis, and therefore a mixture of the “remote” equipment category (which were not studied) and the low temperature self-contained equipment category (which were studied) are taken as a basis for a new spread-sheet for this equipment category. In the techno-economic engineering analysis, ten design options have been consecutively applied:

- high efficiency reciprocating compressor
- permanent split capacitor evaporator fan motor

- brushless DC evaporator fan motor
- enhanced-UA evaporator Coil
- LED Lighting (2013 price and performance levels assumed)
- high-performance door
- enhanced-UA condenser coil
- permanent split capacity condenser fan motor
- brushless DC condenser fan motor
- additional 1/2" of insulation

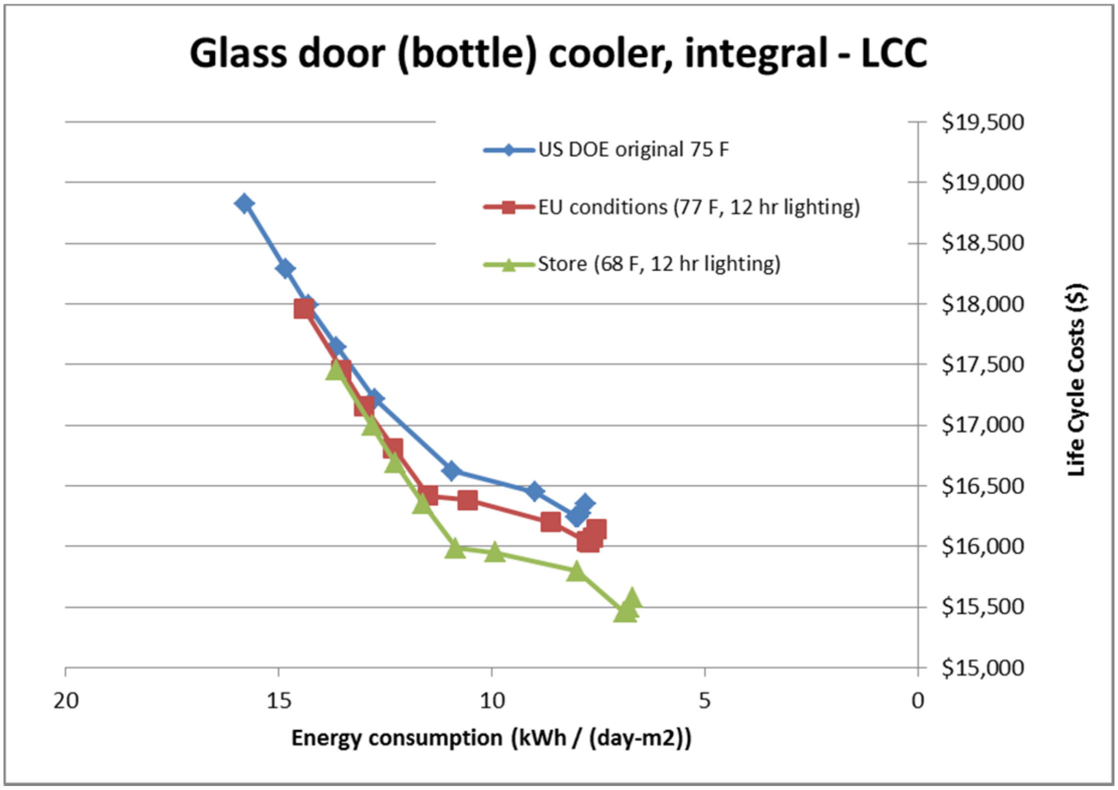
In the techno-economic engineering analysis, not only are the ambient conditions (temperature and relative humidity) varied, but also the number of hours for which the cabinet lighting is switched on. For the ASHRAE condition used in the original US DOE engineering analysis, lighting is switched on 24 hours per day, whereas in the EN-ISO (European) condition and the "in store" condition, lighting is switched on for 12 hours per day, Figure 21.

Figure 21. Estimated sales price (US$) as a function of energy consumption of a glass door vertical, cooling (bottle cooler) integral unit (class IVC4) under typical in-store conditions, EN ISO and US test conditions.



The minimum LCC value is found at design option level 8 for ASHRAE conditions and at design option level 7 for shop conditions, Figure 22. The energy consumption at this level is 7.97 $kWh/m^2/day$ (for ASHRAE conditions and a US 2009 average energy price of 0.10 \$/kWh). At other energy prices (Appendix A), there is a fluctuation in the LCC minimum between design option level 4 (South Africa, low energy price) and level 9 (Brazil, high energy price).

Figure 22. Estimated life cycle cost (US$) as a function of energy consumption of a glass door vertical, cooling (bottle cooler) integral unit (class IVC4) under typical in-store conditions, EN ISO and US test conditions.



Energy performance data on glass door vertical bottle coolers are available in the IEA 4E benchmarking study on commercial refrigeration equipment. The IEA reports do not use TEC/TDA values as a comparison basis, but energy consumption per unit (storage) volume. The base case gross refrigerated volume is 48 ft^3, or 1.36 m^3. At the LCC minimum, the energy consumption is 28.0 kWh/m^3/day, which is equivalent to a TEC/TDA of 7.97 kWh/m^2/day.

Figures 21 and 22 show that an increase in manufacturer selling price of $844 (from $3245 to $4089) would yield annual energy savings of $286 under store conditions, and life cycle savings (discounted at 0% real discount rate over 7 years) of $2005.

For the US Energy Star data set, the IEA 4E benchmarking study reports energy consumption values of between 2.61 and 60.0 kWh/m^3/day, with an average of 8.23 kWh/m^3/day. The difference between the highest and lowest energy consumption values is extreme and unrealistic. The data reported on the California Energy Commission data set have the same characteristics; a minimum consumption of 3.08 kWh/m^3/day and a maximum consumption of 56.7 kWh/m^3/day, with an average of 8.20 kWh/m^3/day.

In this case, at the LCC minimum the TEC/TDA value is 7.97 kWh/m^2/day, which is in line with the average TEC/TDA value as defined by European manufacturers for this equipment class (7.5 kWh/m^2/day). This gives credibility to the idea that the calculated LCC minimum is correct, and the (average) values mentioned in the IEA 4E study are questionable.

Open multi-deck, Remote (RVC2)

Figure 23. Example of an open multi-deck, remote (class RVC2)

In the techno-economic engineering analysis, the following design options are consecutively applied:

- baseline: TDA = 4.95 m^2, Energy consumption 55.6 kWh/day or 11.2 kWh/m2/day
- improved lighting (i.e. moving to super T8 efficacy levels)
- LED lighting (2013 price and performance levels)
- night covers
- PSC evaporator fan motor
- ECM evaporator fan motor
- larger evaporator coil
- increased insulation
- glass doors

The techno-economic engineering analysis for open multi-deck cabinets (remote and integral) is performed using spread-sheets which have been modified from the original USDOE engineering analysis as the night cover design option was not considered in the original analysis, and neither were glass doors applied to open multi-deck (chiller) cabinets. In practice in Europe, however, these options (night covers and glass doors) are very popular. In some cases the application of glass doors has even been made compulsory by national authorities (i.e. in the Netherlands), or is strongly promoted by the national trade associations (e.g. in France). Furthermore, in the revised analysis the cost and performance of LED lighting has been set at a level appropriate for 2013 (which is equivalent to a cost factor of 10 lower than in the original analysis at 2008 price/performance levels).

In the techno-economic engineering analysis results, the analysis is shown without the option of doors or night covers (only at the original DOE or ASHRAE condition), and also with the inclusion of night covers and glass doors at all three conditions (ASHRAE, EN-ISO and Store). The reduced price of LED lighting has also caused a complete revision of the order in which the design options are applied.

The engineering analysis results show the enormous energy saving potential of night covers and glass doors, which was not addressed in the original DOE engineering analysis, Figure 24. The inclusion of glass doors (the last option to be applied), however, also leads to a large price increase. From the LCC analysis, it follows that night covers are always taken into account before the LCC minimum is reached (and thus should always be applied), whereas the addition of glass doors will tend to increase LCC costs, Figure 25.

Figure 24. Estimated sales price (US$) as a function of energy consumption of an open multi-deck, remote (class RVC2) under typical in-store conditions, EN ISO and US test conditions.

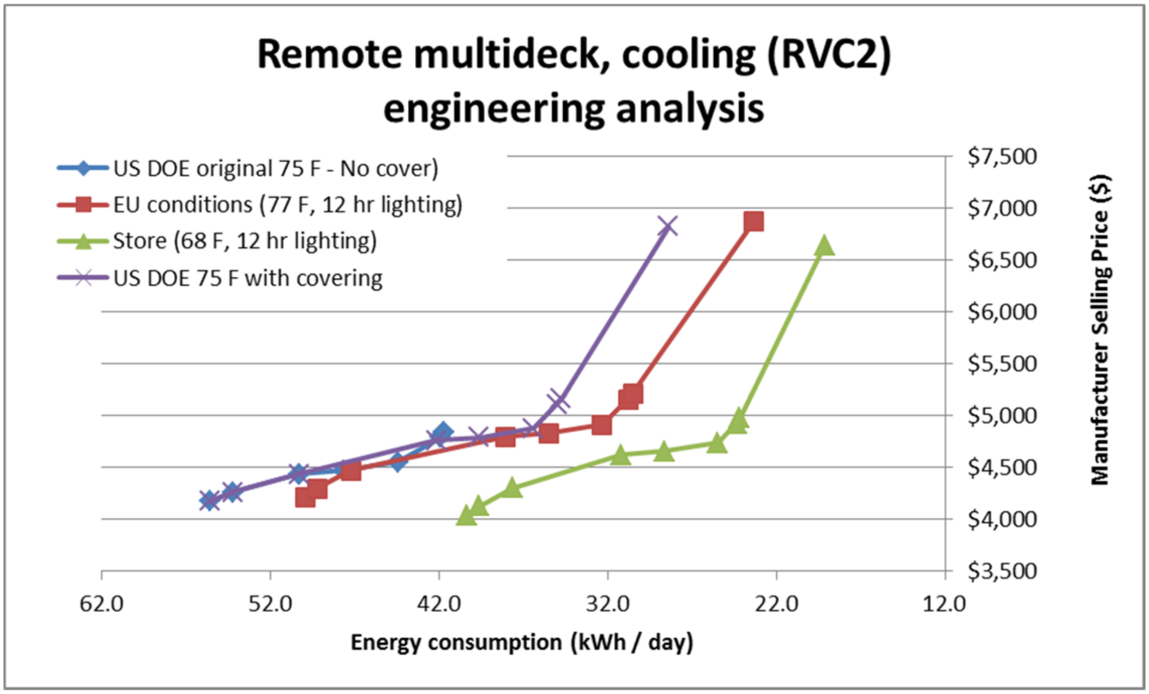
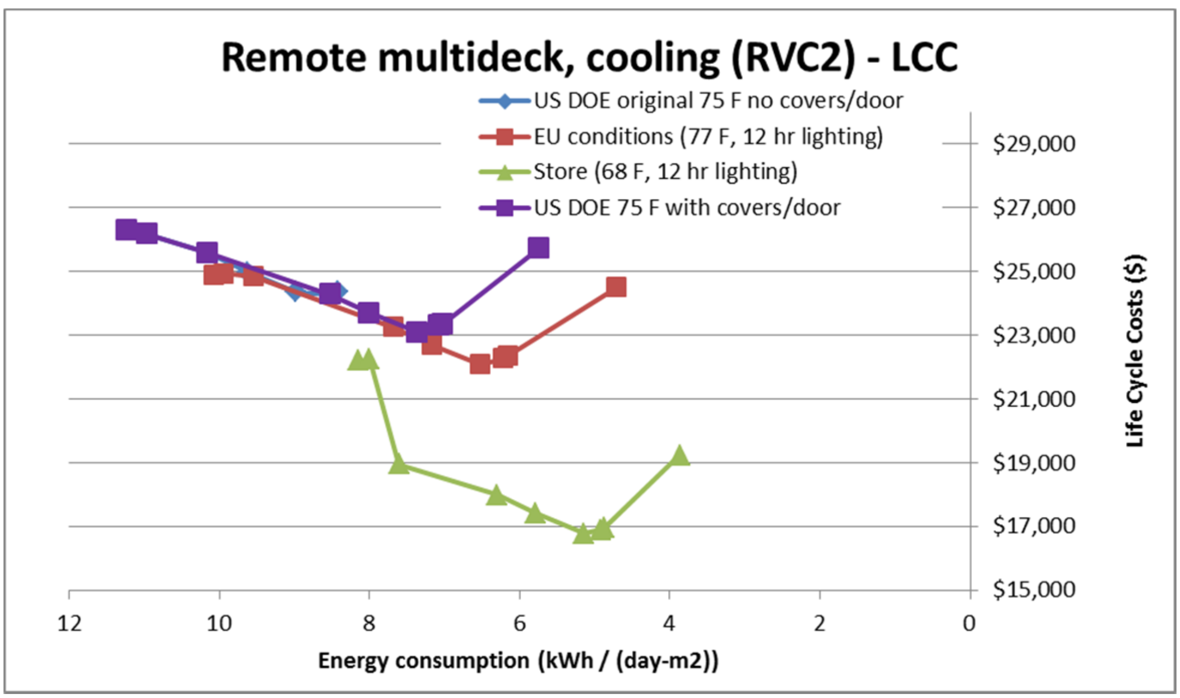


Figure 25. Estimated life cycle cost (US$) as a function of energy consumption of an open multi-deck, remote (class RVC2) under typical in-store conditions, EN ISO and US test conditions.



Figures 24 and 25 show that an increase in manufacturer selling price of $2181 (from $4041 to $6223) would yield annual energy savings of $460 under store conditions, and life cycle savings (discounted at 0% real discount rate over 7 years) of $3219.

The position of the LCC minimum occurred for a TEC/TDA value of 9.21 kWh/m^2/day in the original USDOE engineering analysis, without night covers or glass doors at ASHRAE conditions (24 hours lighting per day) and with the 2008 LED lighting price level. In the current analysis (with updated LED pricing) the LCC minimum is at a value of 8.46 kWh/m^2/day (when excluding night covers). This minimum does almost not change as a function of economy average energy prices (see Appendix A), except for the economies with a very low energy price of South Africa and India, where it rises to 8.98 kWh/m^2/day.

In the analysis where night covers and glass doors are included, it is seen that in all cases with low to medium energy prices the LCC minimum is at design option 5 or 6 (including night covers, but not glass doors). These levels do not differ much in their energy consumption i.e. under ASHRAE test conditions the LCC minimum energy consumption is 7.07 kWh/m^2/day for countries with high energy prices and 7.35 kWh/m^2/day for countries with low energy prices.

Open multi-deck, Integral (IVC2)

Figure 26. Example of an open multi-deck, integral (class IVC2)

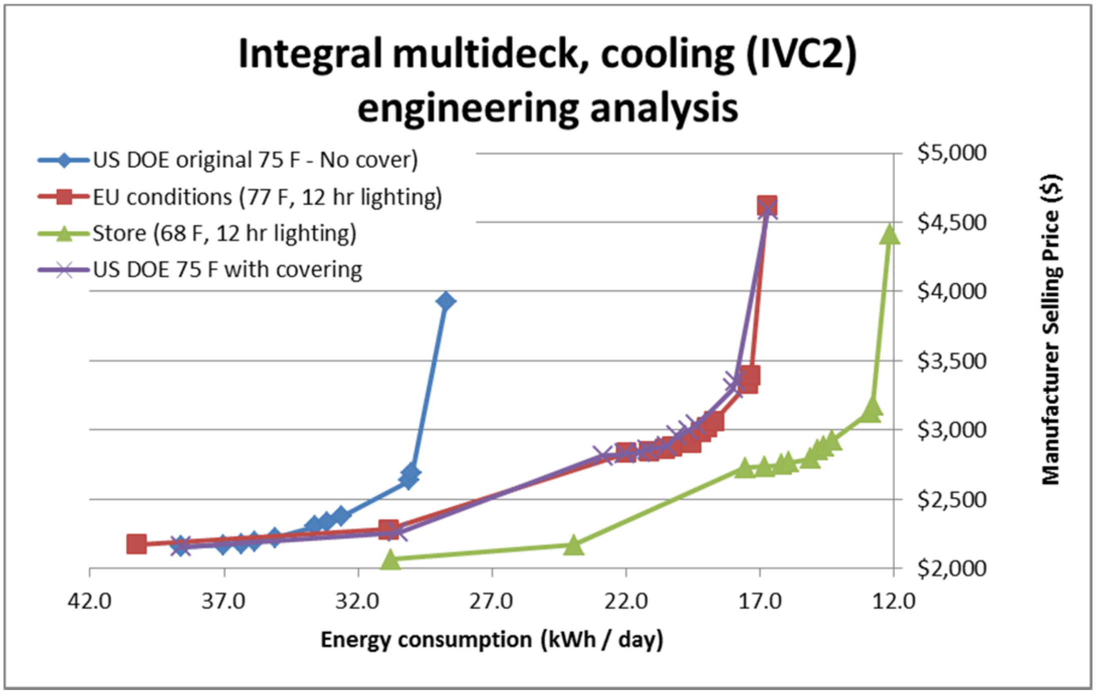
In the techno-economic engineering analysis, the following design options are consecutively applied:

Baseline (TDA = 1.39 m^2, Energy Consumption 38.6 kWh/day, 27.8 kWh/m^2/day)

- improved lighting (i.e. moving to super T8 efficacy levels)
- LED lighting (2013 price and performance assumptions)
- night covers
- permanent split capacitor evaporator fan motor
- permanent split capacitor condenser fan motor
- brushless DC evaporator fan motor
- enhanced-UA evaporator coil
- high efficiency compressor
- brushless DC condenser fan motor
- enhanced-UA condenser coil
- additional 1/2" of insulation
- glass door

For the Integral (self-contained) multi-deck cabinet, the situation is similar to the case of the remote multi-deck cabinets. Here again the economically optimum order of deployment for the design options changes as price and performance of LED lighting is set to the 2013 level, Figure 27.

Figure 27. Estimated sales price (US$) as a function of energy consumption of an open multi-deck, integral (class IVC2) under typical in-store conditions, EN ISO and US test conditions.



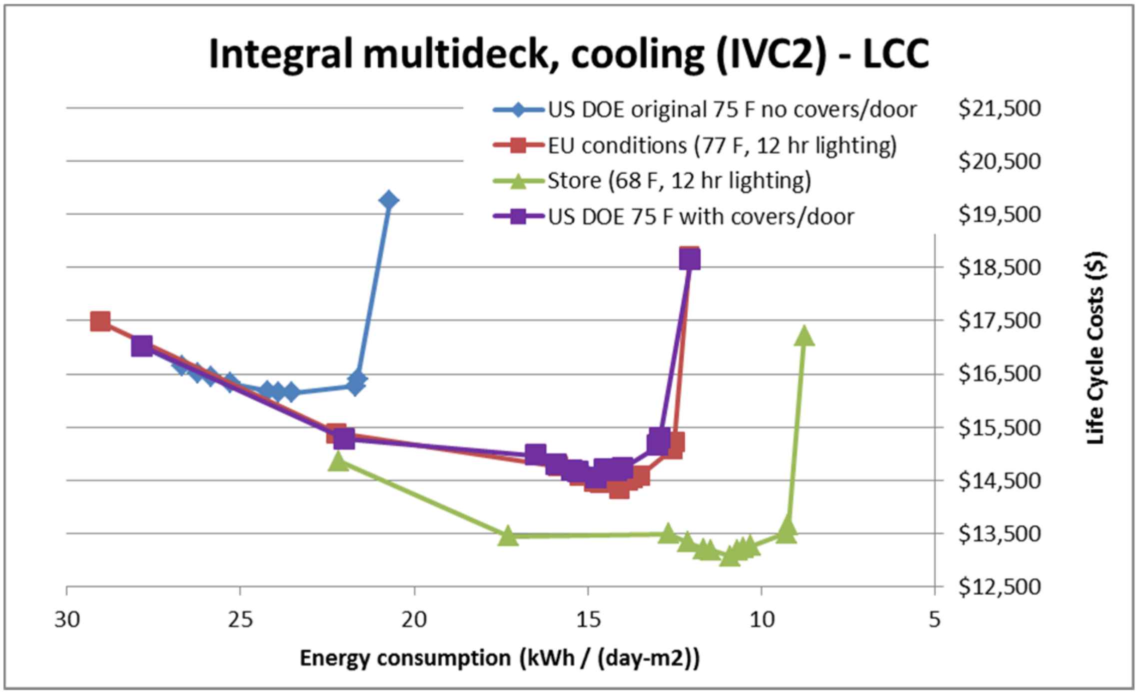
Figures 27 and 28 show that an increase in manufacturer selling price of $727 (from $2065 to $2793) would yield annual energy savings of $256 under store conditions, and life cycle savings (discounted at 0% real discount rate over 7 years) of $1795.

The LCC minima only differ considerably between the original DOE analysis without night covers or glass doors (TEC/TDA at 22.52 kWh/m^2/day) and the analysis with night covers and glass doors (TEC/TDA at 17.97 kWh/m^2/day), Figure 28. This difference is due to the application of night covers, which save 25 % on average cooling load.

It is remarkable that with the IVC2 cabinet (contrary to the RVC2 cabinet), glass doors become a valid option in regions with a high energy price (EU, Japan, Brazil) – see appendix A for LCC results per region.

The California database shows an average TEC/TDA value for integral cooled multi-deck cabinets of 9.03 kWh/m^2/day – which is most probably an artifact due to erroneous data. Other data sources (EU, UK, Australia) shows average TEC/TDA values in the range of 15 to 17 kWh/m^2/day, which is more in line with the calculated LCC minimum.

Figure 28. Estimated life cycle cost (US$) as a function of energy consumption of an open multi-deck, integral (class IVC2) under typical in-store conditions, EN ISO and US test conditions.



2.9 Potential for energy savings at the macro scale

The total energy consumption of reach-in coolers was estimated and forecast for all of the targeted economies for this analysis under the following three scenarios:

- Business As Usual Scenario – this assumes no new policies to promote energy efficiency for reach-in coolers other than those already implemented
- Least Life Cycle Cost Scenario – this assumes that from 2014 onwards all new products sold are at the energy efficiency level associated with the least life cycle cost from an end-users perspective
- Maximum Technical Efficiency Scenario – this assumes all new products sold from 2014 onwards are at the maximum technically achievable efficiency today, i.e. in 2013

The total forecast energy consumption per economy under the Business as Usual Scenario is shown in Table 51 and the total energy savings compared under the Least Life Cycle Cost Scenario and Maximum Technical Efficiency Scenario respectively compared to the Business as Usual case are shown in Tables 52 and 53.

Table 51. Estimated electricity consumption of reach-in coolers under the Business as Usual Scenario

	Electricity consumption (TWh/year)					
	2009	2013	2020	2025	2030	2035
USA	14.2	13.2	14.7	18.1	20.2	22.2
MEXICO	6.6	6.9	8.2	10.0	11.9	13.5
EU	32.9	35.9	42.0	48.3	54.7	60.2
JAPAN	13.5	12.4	12.4	13.6	15.1	16.7
CHINA	3.9	7.3	16.0	22.7	29.7	38.2
INDIA	1.7	2.3	4.2	6.5	9.7	14.1
BRAZIL	3.0	3.5	4.5	5.3	6.2	7.2
RSA	0.4	0.4	0.5	0.7	0.9	1.2
AUSTRALIA	0.7	0.8	0.9	1.1	1.2	1.3
TOTAL	**76.8**	**82.6**	**103.4**	**126.3**	**149.4**	**174.6**

Table 52. Estimated savings in electricity consumption of reach-in coolers under the Least Life Cycle Cost Scenario compared with the Business as Usual Scenario

	Electricity consumption (TWh/year)					
	2009	2013	2020	2025	2030	2035
USA	0.0	0.0	2.3	4.9	5.5	6.1
MEXICO	0.0	0.0	1.4	3.2	3.8	4.3
EU	0.0	0.0	3.9	8.3	9.4	10.4
JAPAN	0.0	0.0	1.7	3.6	4.0	4.4
CHINA	0.0	0.0	3.1	7.2	9.4	12.2
INDIA	0.0	0.0	0.9	2.2	3.3	4.8
BRAZIL	0.0	0.0	0.8	1.7	2.0	2.3
RSA	0.0	0.0	0.1	0.1	0.2	0.2
AUSTRALIA	0.0	0.0	0.1	0.3	0.3	0.4
TOTAL	**0.0**	**0.0**	**14.2**	**31.6**	**37.9**	**45.0**

Total annual energy savings for the Least Life Cycle Cost Scenario are 45.0 TWh of final electricity demand in 2035, which are 26% of the base case value in the same year.

The total energy savings under the Maximum Technical Potential Scenario in 2035 are 55.6 TWh, which are 32% of the base case value.

Table 53. Estimated savings in electricity consumption of reach-in coolers under the Maximum Technical Potential Scenario compared with the Business as Usual Scenario

	Electricity consumption (TWh/year)					
	2009	2013	2020	2025	2030	2035
USA	0.0	0.0	2.8	6.1	6.7	7.4
MEXICO	0.0	0.0	1.7	3.8	4.5	5.1
EU	0.0	0.0	5.0	10.7	12.1	13.4
JAPAN	0.0	0.0	2.0	4.3	4.8	5.3
CHINA	0.0	0.0	3.6	8.5	11.1	14.3
INDIA	0.0	0.0	1.2	3.1	4.6	6.7
BRAZIL	0.0	0.0	0.9	1.9	2.2	2.6
RSA	0.0	0.0	0.1	0.2	0.3	0.4
AUSTRALIA	0.0	0.0	0.2	0.4	0.4	0.5
TOTAL	**0.0**	**0.0**	**17.5**	**38.9**	**46.8**	**55.6**

Modelling and assumptions

Modelling these savings was carried out using a time-series stock model that was adapted from the model used to produce the US national impacts analysis in support of the most recent DOE rulemaking[21]. For each economy, sales data were used to generate stock data assuming an 8 to 12 year product life span (depending on the product, the market and the period). In some cases, sales value time series data were converted into unit sales time series data by using information on the typical unit price per product type (usually derived from US or EU data). Whenever possible the resulting stock values were corroborated against other available stock or unit sales data (this was the case for the USA, the EU, Australia and the RSA) and in these cases the stock/sales estimates from the sales value data were found to agree with the independent estimates within +/-10%, which is considered to be an acceptable level of accuracy given the wholly independent nature of the data sets concerned.

Projections of reach-in cooler stocks were then derived for each type of reach-in cooler based on what was known about the relative sales shares of reach-in cooler types in each market. In many cases this data would either be almost absent (Brazil, China, India), or mostly only available in aggregate forms (e.g. for integral and remote units – Japan and RSA), or would have to be estimated from the relative prevalence of model (rather than sales) data (Australia, Mexico, Japan, RSA). Unit sales information by reach-in cooler type was only available for the EU and USA.

Energy consumption per reach-in cooler type was derived by first adjusting all test procedure energy consumption data to values that would be expected in situ (i.e. in the shops where the appliances are installed) through application of the ambient temperature correction functions explained in section 2.8. The consumption by product type was then adjusted for: a) any known differences in the average product size by economy from the US data, b) any known differences in efficiency by product type compared to the US average. Both of these sets of derived estimates have considerable uncertainties attached to them. Differences in average product size are calculated compared to the US model from the various data sources assembled in the study and are described in section 2.4. In some cases these databases are very sparse and so it is likely they only give a poor indication of the actual market average product types for the economies they come from. Estimates of the average difference in product efficiency are also highly uncertain in many cases as the data sets used are

[21] http://www.regulations.gov/#!documentDetail;D=EERE-2006-STD-0126-0080

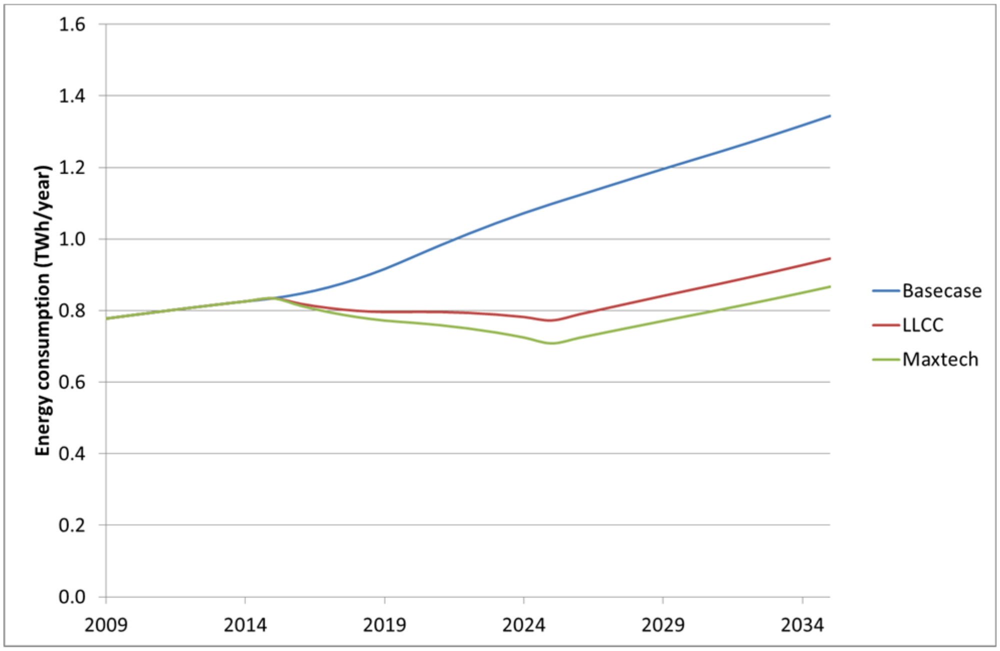
patchy or incomplete. Apart from the USA, the best data sets are for Europe and Australia. Good product data were available for one manufacturer in Japan. A relatively large data set of certified products was also available for Mexico but this only included integral reach-in cooler types and hence was only partially useful. A very small amount of model data was available for China but otherwise it was assumed that Chinese products respect the minimum efficiency standards and are distributed among the label classes in the same manner as the products in the small dataset. There was only a very small amount of data available for Brazil from one producer and it is likely this is not representative of the market as a whole. In the case of India, there were no energy performance data available and thus it was arbitrarily assumed that all products are at the efficiency level of the baseline (least efficient) product in the US DOE rulemaking's technical support document. The uncertainty in all these factors could result in there being significant errors in the base case (business as usual) efficiency level and unit average energy consumption assumed in the Business as Usual Scenario; however, the results are still thought to be helpful in framing the rough magnitude of reach-in cooler energy consumption in the absence of better data.

For both the Least Life Cycle Cost scenario and the Maximum Technical Efficiency Scenario it is assumed that new products sold up to 2014 are at the Business As Usual Scenario efficiency level and that after 2014 they are at the efficiency associated with the Least Life Cycle Cost or the Maximum Technically Achievable level respectively. The analysis presented in section 2.8 and Appendix A is used to derive these values but in the case of the Least Life Cycle Cost scenario the efficiency level of LLCC varies by economy depending on the average electricity tariff (for the sake of simplicity product costs are assumed to be the same as in the USA for all economies except the EU (where EU data were available and used) although adjusted for differences in average product size – thus variations in labour, transport and material costs are not considered and nor are variations in production/distribution margins and other local factors considered). For both the LLCC and Maximum Technical Efficiency Scenarios it is (conservatively) assumed that there is no ongoing learning effect i.e. that the incremental costs of more efficient products remain unchanged over time and that there is no long term improvement in the maximum efficiency level attainable. Neither of these assumptions is likely to be accurate as the incremental cost of efficiency will probably decline over time as new technology enables higher efficiency products to be produced at lower cost.

Figures showing the results of these three scenarios for each economy are shown in the next sections.

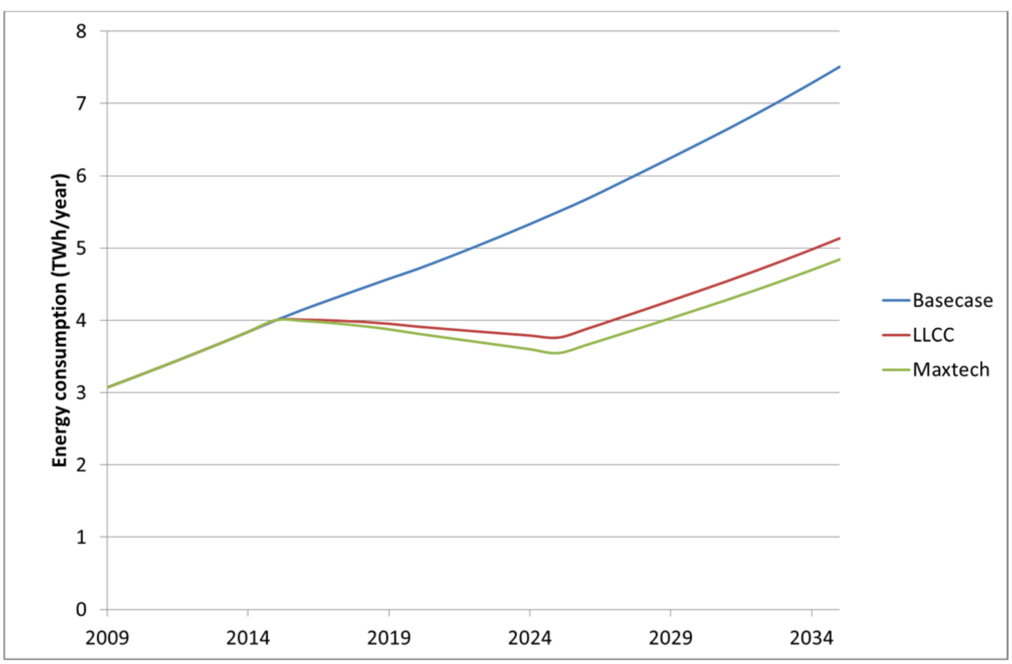
Australia

Figure 29. Australia estimated energy consumption for Reach-in Coolers under Business as Usual, Least Life Cycle Cost and Maximum technical efficiency scenarios.



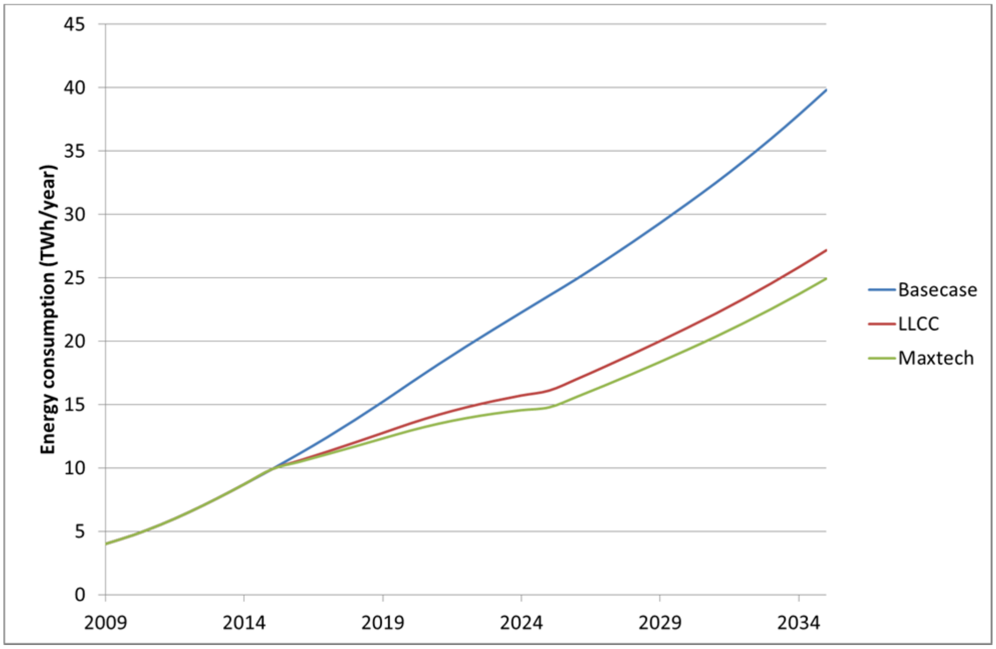
Brazil

Figure 30. Brazil estimated energy consumption for Reach-in Coolers under Business as Usual, Least Life Cycle Cost and Maximum technical efficiency scenarios.



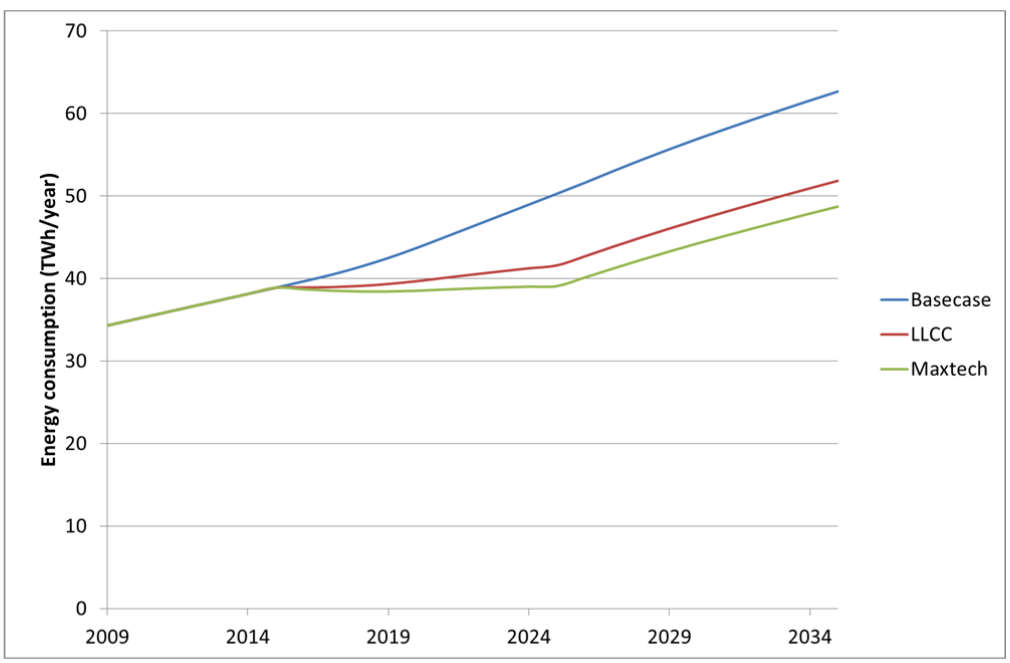
China

Figure 31. China estimated energy consumption for Reach-in Coolers under Business as Usual, Least Life Cycle Cost and Maximum technical efficiency scenarios.



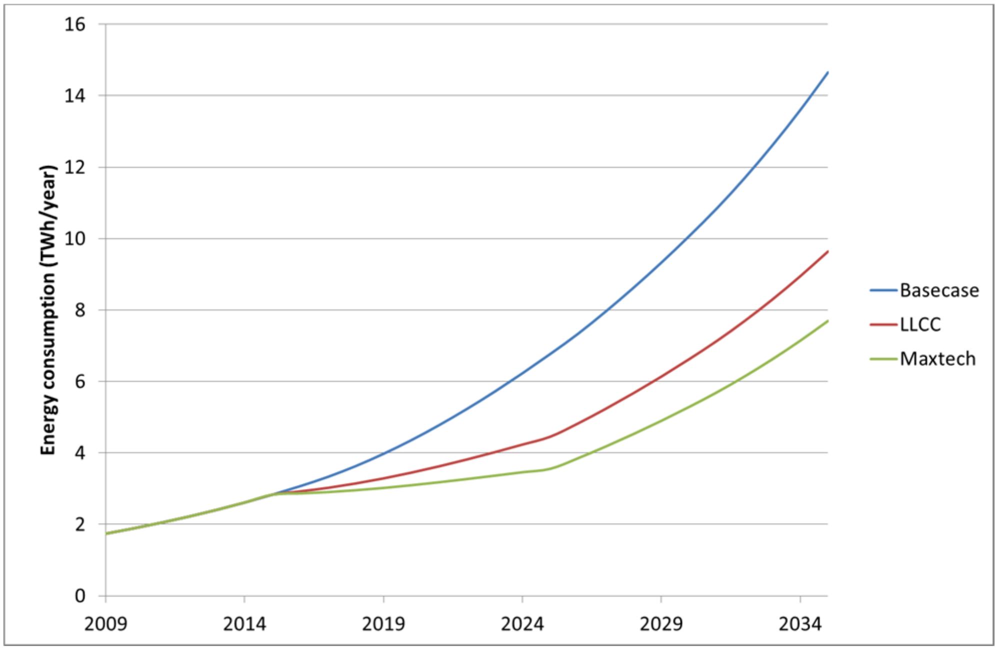
Europe

Figure 32. European Union estimated energy consumption for Reach-in Coolers under Business as Usual, Least Life Cycle Cost and Maximum technical efficiency scenarios.



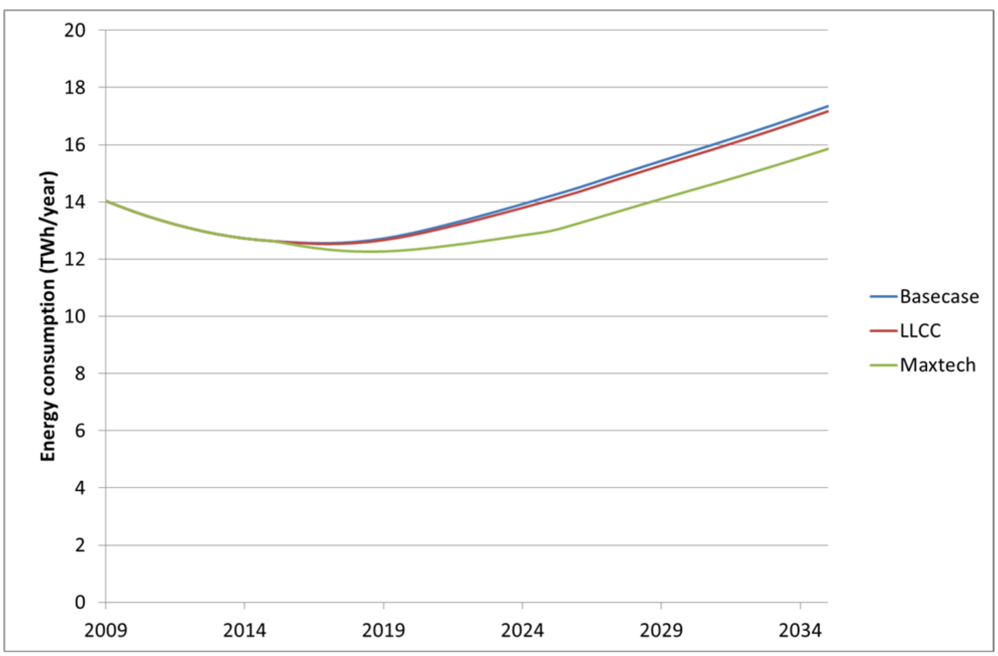
India

Figure 33. India estimated energy consumption for Reach-in Coolers under Business as Usual, Least Life Cycle Cost and Maximum technical efficiency scenarios.



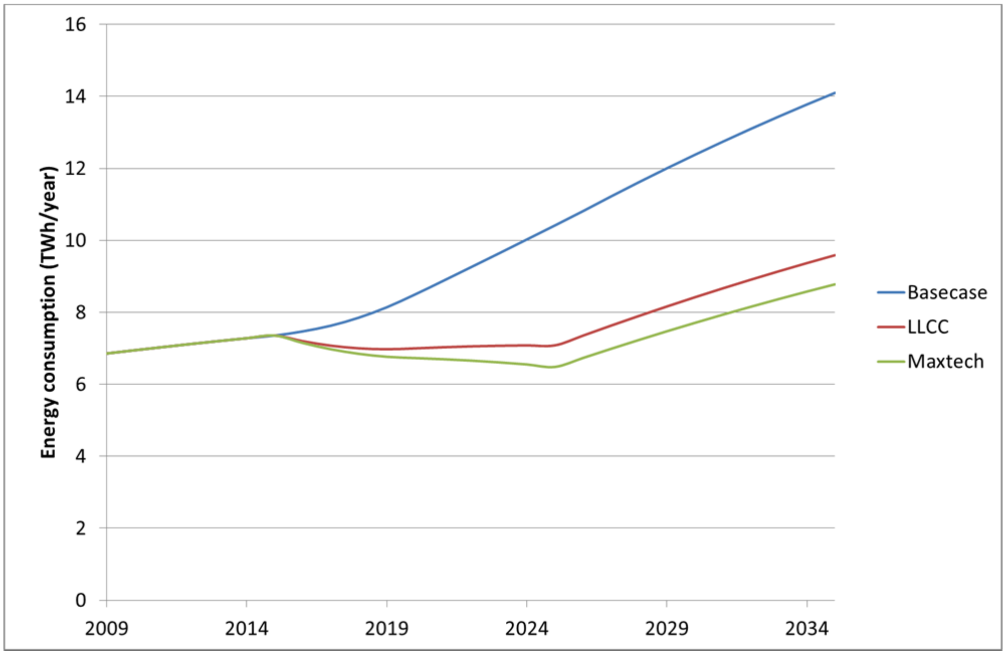
Japan

Figure 34. Japan estimated energy consumption for Reach-in Coolers under Business as Usual, Least Life Cycle Cost and Maximum technical efficiency scenarios.



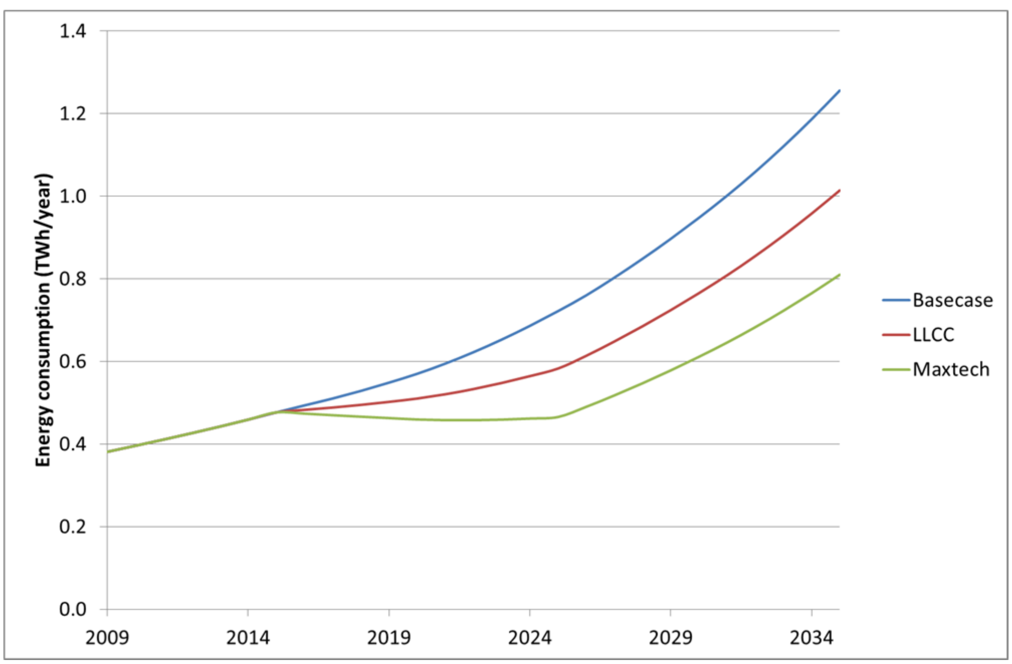
Mexico

Figure 35. Mexico estimated energy consumption for Reach-in Coolers under Business as Usual, Least Life Cycle Cost and Maximum technical efficiency scenarios.



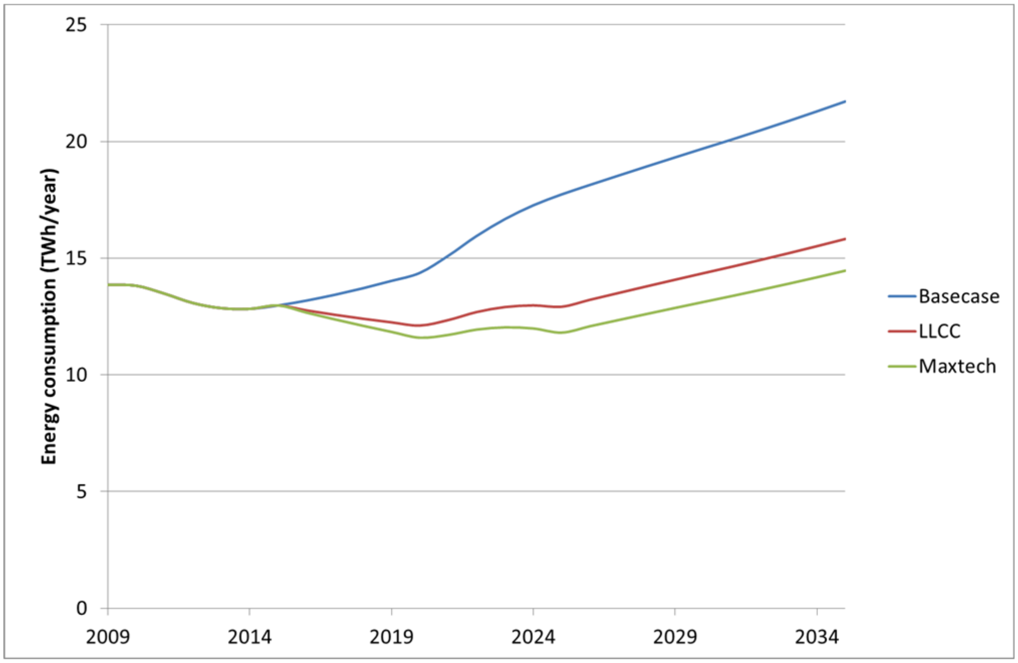
South Africa

Figure 36. South Africa estimated energy consumption for Reach-in Coolers under Business as Usual, Least Life Cycle Cost and Maximum technical efficiency scenarios.



USA

Figure 37. United States estimated energy consumption for Reach-in Coolers under Business as Usual, Least Life Cycle Cost and Maximum technical efficiency scenarios.



Implications

Overall this analysis shows the strong potential to deliver greater savings through more proactive policy measures. The current mix of policies is rather patchy with many economies not having energy labelling or MEPS for any reach-in cooler types.

Clearly countries that have no standards or labelling policy measures for retail display cabinets such as Brazil, the EU, India and Japan have a strong potential to save energy by introducing such measures, and the EU is in the process of developing such measures. Countries like China and Mexico which have measures for some equipment types (remote and integral) units respectively would benefit from developing them for all retail display cabinet categories. Interestingly, the markets with standards and labelling in place are not obviously leading the field in retail display cabinet energy efficiency. South Africa, nominally has standards in place for some reach-in cooler types but they do not seem to be up to date nor mandatory. The US DOE rulemaking process precluded consideration of some high efficiency design options such as night covers and doors that are routinely used in some other markets and could be obliged through regulation. The Australian market does not appear to be any more efficient than the European market, which is not yet regulated. This suggests there is more to be done in all economies to increase the energy efficiency of the market.

3. Refrigerated vending machines

This section of the report addresses refrigerated vending machines and follows the same structure as for the reach-in coolers. It involves:

- Identification of the national test procedures applied in the target economies and their equivalence to other commonly used international or national test procedures
- Examination of similarities and differences in how the efficiency metrics are derived and applied in the different economies
- Conduct of a comparison of the test procedures, and identification of potential issues that are likely to affect the comparability of nominal test results
- Comparison of the differences in the testing procedures and protocols to assess the expected impact on rated energy performance associated with variations in: testing conditions, testing methods, calculation methods for efficiencies, uncertainty of measurements, tolerances, etc.
- Description of the energy efficiency policies currently in place
- Analysis of the sales and stocks of vending machines
- Conduct of a techno-economic energy engineering analysis to determine cost effective energy savings potentials
- Derivation of long range economy wide energy consumption scenarios.

3.1 Types of refrigerated vending machine

Refrigerated vending machines are commercial refrigerated cabinets designed to accept consumer payments or tokens to dispense chilled or frozen products without on-site labour intervention. Vending machines are most often plug-in appliances.

There are three main types: can, drum and spiral. The prevalence and functionality of these types varies by economy and investigations presented later in the report suggest variation in the proportion of primary types is likely to be a significant cause of variation in nominal benchmarks of energy efficiency from one economy to another. Figure 38 shows a spiral (multi-purpose) vending machine, the most common type sold in the EU.

In the USA a distinction is made by type of vending machine depending on whether it is a class A machine (i.e. has a glass front) or a class B machine (has an opaque front). This distinction obviously affects how much of the produce is displayed directly at the point of sale but this in turn has an influence on its energy consumption as it is more viable to cool product just prior to sale (via zone cooling) for opaque (class B) machines than it is for transparent class A machines. The spiral vending machines shown in Figure 38 are invariably transparent and do not use zone cooling.

Figure 38. Spiral vending machine, with a net volume of 750 litres, operating in temperature class M2 (-1°C to 7°C), using R134a as refrigerant, with a product life of 8.5 years. Plug-in.

3.2 Energy performance test procedures

There is no international test procedure for the energy performance of vending machines but the existing test procedures are summarised in Table 54.

Table 54. Energy performance test procedures used for vending machines

Canada	CSA	CAN/CSA-C804-09:2009 Energy performance of vending machines
Europe	EVA	EVA-EMP Version 3.0B: 2011 (an industry association voluntary test procedure)
Japan	Japanese Standard Association	IEC 60335-2-75:2012 Household and similar electrical appliances - Safety - Part 2-75: Particular requirements for commercial dispensing appliances and vending machines
		JIS B 8561:2007: Vending machines -- Test methods
USA	ANSI	32.1(2010): method of testing of rating vending machines for sealed beverages
		NSF/ANSI 7-2009 NSF International Standard/ American National Standard for Food Equipment ? Commercial refrigerators and freezers

Formally adopted cold vending machine energy performance test standards exist for Australia, Japan and the USA, but not for Brazil, China, Europe, India or South Africa. The most established test standard is ASHRAE Standard 32.1-2004, "Methods of Testing for Rating Vending Machines for Bottled, Canned, and Other Sealed Beverages" which underpins minimum efficiency performance standards (MEPS) (incl. proposed) and/or labelling in the USA (including separate requirements in California) and Canada. The Australian and New Zealand test procedure is also based on this. Under ASHRAE 32.1 energy consumption is measured in kWh per day in the idle state i.e. the energy consumed during vending actions and reloading actions is not considered. The functionality of the machine is sometimes expressed through a measure of capacity in terms of number of products (bottles/cans) used, and sometimes in terms of the internal volume (litres or dm^3).

In Europe, manufacturers and importers may employ the voluntary European Vending Association's Energy Measurement Protocol (EVA-EMP) which is used in a voluntary energy labelling scheme as described in section 3.3.

The IEA 4E mapping reports suggest the following definition for cold vending machines: Self-contained refrigerated systems designed to accept consumer payments or tokens to dispense pre-packed beverages (cans/bottles/food packets) at between 3°C and 12°C without on-site labour intervention.

An analysis of the existing test performance rating systems used in the USA and Europe (the voluntary EVA-EMP scheme) shows that they only consider energy consumption in the idle mode and fail to reward the inclusion of presence detection or timing devices that power down the vending machine in periods of low demand. As a result they do not capture the benefits of the most promising energy saving feature. It will be important for any new pending test procedures (e.g. in Europe and ISO but also in all economies that currently do not have a test procedure) to rectify this by introducing a duty-cycle approach to measurement and rating vending machine energy performance. Future revisions of the US test procedure for MEPS should also consider making this change.

There are also significant doubts about how best to design an energy-efficiency metric for vending machines that will capture the real benefits from machines in situ and their broader place in the food/beverage cold chain. Vending machine types used around the world vary in their prevalence and function. In the USA and Australia there is a relatively high proportion of closed (opaque) drinks vending machines whereas in Europe the most common type are multi-function transparent vending machines that can serve a variety of drinks, food or snacks. Japan is comfortably the largest single vending machine market, however, and it has a variety of types depending on the service function. The type of machine has an intrinsic impact on its energy consumption as transparent multi-purpose machines, which are common in the EU, tend to require more energy to provide their service as the entire interior contents are on display and cooled simultaneously, whereas with opaque machines it is only necessary to cool products that are likely to be served imminently and the remaining drinks can be kept at ambient temperature. Furthermore, the frequency of stocking will have a significant impact on the energy used in the entire cold chain to provide the chilled drinks/food service. As a result the efficiency metric of energy used per 300 cans stored that was used in the IEA 4E mapping and benchmarking exercise will fail to capture both the difference in service and the overall impact of the service on the energy used in the cold chain. More work therefore needs to be done to devise an appropriate energy efficiency metric for vending machines that properly delineates service and the broader cold chain energy use impacts.

Adjusting energy consumption for differences in test procedures

A detailed point by point comparison of ASHRAE 32.1 and EVA 3.0a and 3.0b (EU) test standards for vending machines is provided in the SEAD report “Technical evaluation of national and regional test methods for commercial refrigeration products” (2013), along with the details of the test methods in Japan, Australia and Canada.

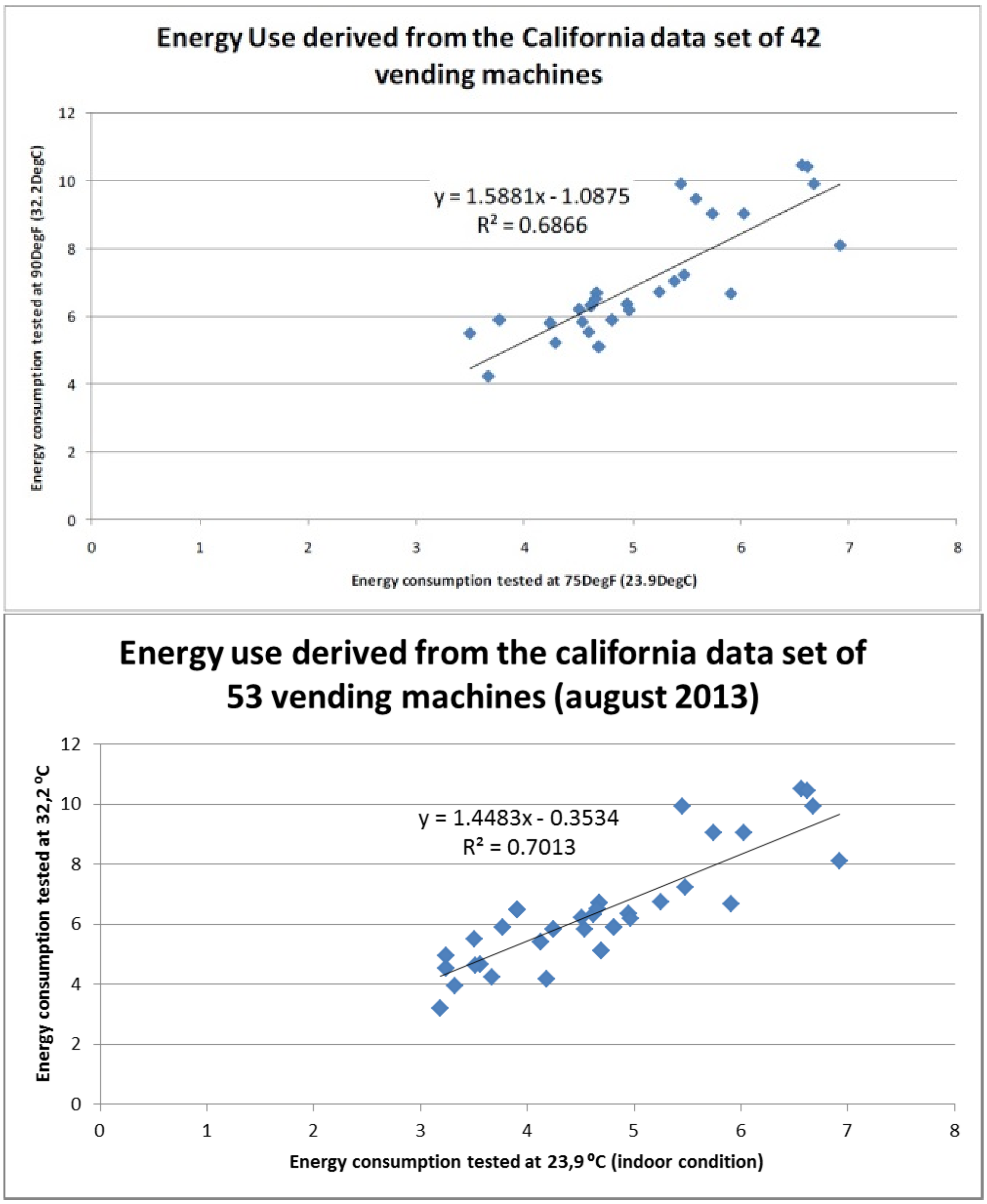
The “outdoor” test condition of 32 ^{o}C or 32.2 ^{o}C is almost identical in all the standards except Japan which uses 15 ^{o}C, but there is a difference in the indoor test condition where the USA, Canada and Australia use 23.9^{o}C or 24^{o}C (Australia), Europe uses 25 ^{o}C, and the Japanese test procedure does not specify a separate indoor temperature.

The design storage temperature for vended product is the same for the ASHRAE, Canadian and Australia standards (2.2 ^{o}C), whereas the Japanese standard specifies 4 ^{o}C while the EVA-EMP test procedure does not consider the product temperature but rather the air temperature inside the cabinet, at manufacturer specified settings.

In older regulations or labelling requirements (See section 3.3) the metric used to express the energy performance was energy consumption per day (kWh/24 hours) in relation to the number of cans the machine can hold. In more recent policy specifications, however, there has been a tendency to relate the energy consumption per day (kWh/24 hours) to the internal volume, instead of to the number of cans.

The IEA 4E Benchmarking report for vending machines concludes that to compare test results produced under the different standards, it is only necessary to apply a correction for ambient temperature (i.e. to correction for differences in the indoor to outdoor conditions). The benchmarking report derives a formula based on a regression of the California data set for vending machines, as shown in the top part of Figure 39.

Figure 39. Energy consumption of California vending machines from IEA 4E report (top) and updated in August 2013 (below).



This formula is very sensitive to changes in the data set, as can be seen from Figure 39 where the top figure is the regression made in the IEA 4E benchmark report, and the bottom figure shows a regression performed on a more current version of the same database. Moreover, the regression type chosen in the benchmark report is linear with an offset, whereas a simple linear regression without an offset provides equally good results. A simple regression without offset is more in line with the actual physics underpinning vending machine energy use, is easier to use, and can be applied more robustly over a wider application range. The simple regression found in the recent analysis of the California data set is:

$$E\ (32.2\ ^oC) = 1.373 * E\ (23.9\ ^oC)$$

and has an $R^2 = 0.6993$ as opposed to an $R^2 = 0.7013$ for a linear regression with offset. Making the assumption that in general 70 % of the energy is used for cooling and the remaining 30 % is for lighting etc.[22], gives:

$$E\ (32.2\ ^oC) = 0.30 * E\ (23.9\ ^oC) + 0.70 * E\ (23.9\ ^oC) * 1.533$$

where the energy used for lighting etc. remains constant over the difference in ambient temperatures used in the test, whereas the energy for refrigeration increases by 53.3 %, adding up to an overall consumption increase of 37.3 % (as indicated by the regression line). The increase in energy use per ^{o}C in moving from 23.9 ^{o}C to 32.2 ^{o}C is thus 3.8 %.

The IEA 4E benchmark report reports an apparent discrepancy between the "refrigeration rule of thumb" of 2-3 % energy consumption increase per ^{o}C, and the empirical value of 37% overall increase of energy consumption (or actually 53.3 % increase in refrigeration consumption as demonstrated above). However, this rule of thumb is only intended to apply to the compressor C.O.P. when the load remains constant and the temperature difference between the condenser and ambient remains constant. In reality, the load increases considerably as the ambient temperature increases and the condenser to ambient temperature difference may also increase. Therefore, there is not really a discrepancy between the rule of thumb based on refrigerator physics and the empirical values, even when the empirical data suggest an average increase of 3.8% per ^{o}C in moving from an ambient temperature of 23.9 ^{o}C to 32.2 ^{o}C.

Therefore in place of the ambient temperature energy conversion formula given in the IEA 4E report it is recommended to use a fixed percentage correction factor of +37 % to adjust the average vending machine energy consumption values when changing the ambient test conditions from 23.9 ^{o}C (indoors, under ASHRAE test conditions) to 32.2 ^{o}C (outdoors, under ASHRAE test conditions).

Similarly, when adjusting energy consumption values from 25 ^{o}C ambient (under EU indoor conditions) to 32.2 ^{o}C (US outdoor condition) it is recommended that a correction factor of +31 % be applied as follows:

$$E\ (32.2\ ^oC) = 0.30 * E\ (25.0\ ^oC) + 0.70 * E\ (25.0\ ^oC) * 1.45 = 1.31 * E\ (25.0\ ^oC)$$

[22] For class B vending machines, the cooling energy consumption comprises 65 % - 76 % of the total energy consumption according to DOE studies. For spiral vending machines (class A) the variable cooling energy consumption of the EU Ecodesign Lot 12 base case comprises 69.9 % of total energy consumption at 25 ^{o}C.

The effect of using the IEA 4E benchmark report correction formula instead of the more simple correction proposed here for correcting energy use of European vending machines is that for EU machines with low energy consumption the calculated consumption is too low, whereas for EU machines with high energy consumption the corrected consumption is too high. At the energy consumption levels for EU vending machines used in the IEA 4E benchmarking study (averages of 6.15 kWh/day and 7.49 kWh/day at US outdoor conditions) these differences are small, in the order of + or -1.5 %.

The prevailing test standards measure energy consumption in "idle" state i.e. without taking account of the energy used by when vending products. This favours the type of machines where only part of the contents are held at a low temperature (class B), as the actual cooling down of products from the "warm" condition to the "cold" condition is not taken into account. In the most recent US DOE efficiency standards for vending machines (section 3.3) the Maximum Daily Energy Consumption (MDEC) is specified separately for class A and class B machines (where class A are fully cooled, and class B are zone cooled) so these standards do not "favour" class A or class B type vending machines

The high temperature used in the outdoor condition (32.2^{o}C or 32^{o}C) places an elevated emphasis on the energy consumption for refrigeration, as opposed to energy consumption for lighting and the payment mechanism. In reality the average year round temperatures are much lower in the economies where these outdoor temperature conditions are specified. The reason such elevated temperatures have been chosen is likely to be to minimise test costs because the same test can be used to verify that the appliance is capable of maintaining the required interior temperature under a high ambient temperature as to derive an energy consumption value, however, the consequence is an unrealistically high outdoor energy consumption and a test procedure that will give disproportionate benefit to design measures that improve refrigeration efficiency as opposed to temperature independent aspects of vending machine energy consumption.

To consider the importance of this effect a calculation has been made to show the difference in actual average consumption and the consumption at the standard testing temperature. For this calculation, actual hourly temperature values during one year (2012) were taken for three locations, and for each hour of the year the corresponding energy consumption was calculated. The condensing temperature was set to have a minimum value of 20 ^{o}C (because when the condensing temperature becomes too low, the refrigeration cycle will not work correctly). The calculation results are provided in Table 55.

Table 55. Estimated energy consumption of vending machines at different ambient temperatures

Location	Energy consumption		
	25 ^{o}C	32.2 ^{o}C	In location climate (hourly calc.)
Houston, USA	6.00 kWh/day	7.78 kWh/day	4.99 kWh/day (average 20.5 ^{o}C)
Chicago, USA	6.00 kWh/day	7.78 kWh/day	3.28 kWh/day (average 10.1 ^{o}C)
Paris, France	6.00 kWh/day	7.78 kWh/day	3.03 kWh/day (average 11.0 ^{o}C)[23]

In these calculations 70 % (4.2 kWh/day) of the average energy consumption of 6.00 kWh/day at 25^{o}C is assumed to be for refrigeration, and 30 % (1.8 kWh/day) is for other functions, mainly lighting. When we consider that the lighting consumption is invariant in different climates, we can conclude that under average Parisian conditions, for example, only 1.2 kWh/day of the real energy consumption (3.03 kWh/day) will be for refrigeration, which is just 40 % of the total. Making this

[23] In Paris the average temperature is higher than in Chicago, and still the average consumption is lower because there are less hours where the condenser temperature is clipped.

adjustment for more representative in situ conditions will dramatically influence life cycle cost (LCC) curves, as refrigeration related options will be far less economical to implement compared to how they appear under the existing standard test conditions. Therefore, it is recommended that any techno-economic energy engineering analysis for determining LCCs be performed at more realistic "real life" ambient conditions. This can be done without changing standard test conditions through application of the adjustment factors set out above.

As previously mentioned standard test conditions are in idle state, and do not cover, "selling" actions or refills. Actual sales of beverages do not increase the energy consumption noticeably. Typical beverage sales volumes are reported to range from 50-500 cans/week in EU vending machines (EU Ecodesign Lot 12 report). At a sales level of 100 cans per week the cooling power needed to cool down replacement cans from +25 ^{o}C to +4 ^{o}C loaded into the refrigerated zone in class B vending machines is about 1.7 Watts. This amounts to less than 1% of the overall energy consumption and thus a test procedure focused on idle mode consumption will only slightly underestimate actual consumption.

However, an issue that is not encouraged (i.e. rewarded with a lower rated energy consumption) under any of the current testing standards is the reduction of lighting levels when customers are not present. This is a significant savings option as lighting is already 30 % of the energy consumption under test conditions, and even more in real life conditions. Devices are on the market which can accomplish this function, but they are sold as "add-ons" with a price level that is much higher than would be expected were the function to be incorporated by the manufacturer (which would also avoid the add-on installation costs). None of the current test standards encourage manufacturers to do this, but programmes such as Energy Star do require such a 'low power mode" for periods of extended inactivity, see section 3.3 (USA).

3.3 Energy efficiency policies

Australia

The MEPS specified in AS 1731 for commercial refrigeration equipment do not apply to refrigerated vending machines or cabinets intended for use in catering and similar non-retail applications. However, MEPS for vending machines are reported to be under consideration.

Brazil

Brazil is not thought to have any energy efficiency requirements for vending machines.

China

China is not thought to have any energy efficiency requirements for vending machines.

Europe

The Commission is developing Ecodesign requirements for vending machines. In addition the EVA (European Vending Association) has developed a voluntary energy labelling scheme for vending machines that uses test results produced according to their voluntary test procedure (EVA-EMP), Table 56.

Table 56. Indicative energy consumption for vending machines (typical internal volume of 500 L for non-perishable food/drink) in each energy label class, according the EVA-EMP voluntary energy labelling scheme

Energy label class	Energy consumption kWh/24h less than	Power kW less than
A+	3.68	0.15
A	4.82	0.20
B	6.58	0.27
C	7.89	0.33
D	8.77	0.37
E	9.65	0.40
F	10.96	0.46
G	>10.96	>0.46

India

India is not thought to have any energy efficiency requirements for vending machines.

Japan

Japan applies "Top Runner" programme requirements for vending machines which are a type of minimum fleet average energy efficiency requirement that all suppliers of vending machines onto the Japanese market are required to meet.

Scope

Vending machines for canned/bottled beverages, beverages in paper containers, and beverages served in cups, all of which are specified in JIS B8561. However, the following products shall be excluded.

1) those intended to be used only on ships

2) those intended to be used only on railway cars

3) cup type beverage vending machines that cool beverages (raw materials) by means of electronic cooling (e.g. Peltier cooling)

4) machines of the countertop type

5) machines for alcoholic beverages other than beer (including low-malt beer).

Energy consumption measurement

(1) For vending machines whose target fiscal year is FY 2005 and each subsequent fiscal year (until FY2011) the annual energy consumption (kWh/year) is measured in accordance with the method specified in JIS B8561 (2000).

(2) For vending machines whose target fiscal year is FY 2012 and each subsequent fiscal year the annual energy consumption (kWh/year) measured in accordance with the method specified in JIS B8561 (2007).

Top Runner energy performance thresholds

In the target fiscal year and each subsequent fiscal year, energy consumption efficiency in each category shall be at or lower than the target standard value.

Table 57. Categories of vending machines considered in Japan's Top Runner requirements

Beverages to be Sold	Target fiscal year and Target standards
Canned/bottled beverages	FY 2005 and subsequent fiscal year (until FY 2011): Target standards (1) shall be complied with.
	FY 2012 and each subsequent fiscal year: Target standards (2) shall be complied with.
Beverages in paper containers	FY 2012 and each subsequent fiscal year: Target standards (2) shall be complied with.
Beverages served in cups	FY 2012 and each subsequent fiscal year: Target standards (2) shall be complied with.

Table 58. Top Runner requirements for vending machines for canned/bottled beverages whose target fiscal year is FY 2005 and each subsequent fiscal year (until FY 2011) in Japan

Category		Calculation formula of standard energy consumption efficiency
Type of Vending Machine	Category name	
Machines serving cold only, or Machines serving hot or cold	1	$E=0.346V+465$
Machines serving hot and cold(Internal depth is below 400 mm)	2	$E=2.18V_a-214$
Machines serving hot and cold(Internal depth is 400 mm or greater)	3	$E=0.876V_a+527$

1. "Machines serving cold only" refers to vending machines that refrigerate the products sold.

2. "Machines serving hot or cold" refers to vending machines that refrigerate or warm the products they sell.

3. "Machines serving hot and cold" refers to vending machines which have warm section and cold section separated by internal partitions, so that the products sold are kept refrigerated or warmed respectively.

4. E, V, and Va are the following numeric values.

E = Standard energy consumption efficiency (unit: kWh per year)

V = Actual internal volume (indicates the numeric value calculated from the internal dimensions of the goods storage area) (unit: litre)

Va = Adjusted internal volume (indicates numeric value acquired first by multiplying the actual internal volume of the hot storage compartment by 40, which is divided by 11, and then by adding the result to the actual internal volume of the cold storage compartment) (unit: litre)

Table 59. Top Runner requirements for vending machines whose target fiscal year is FY 2012 and each subsequent fiscal year in Japan

Category: Beverages to be sold	Category: Type of Vending Machine		Category name	Calculation formula of standard energy consumption efficiency
Canned or bottled beverages	Machines serving cold only, or Machines serving hot or cold		I	$E=0.218V+401$
	Machines serving hot and cold (Internal depth is below 400 mm)		II	$E=0.798V_a+414$
	Machines serving hot and cold (Internal depth is 400 mm or greater)	Without electronic money processing device	III	$E=0.482V_a+350$
		With electronic money processing device	IV	$E=0.482V_a+500$
Beverages in paper container	Type A (Dummy samples are used for selling goods)	Machines serving cold only	V	$E=0.948V+373$
		Machines serving hot and cold (having two internal compartments)	VI	$E=0.306V_b+954$
	Type B (Actual goods are used for visual display and selling goods)	Machines serving hot and cold (having three internal compartments)	VII	$E=0.63V_b+1474$
		Machines serving cold only	VIII	$E=0.477V+750$
		Machines serving hot and cold	IX	$E=0.401V_b+1261$
Beverages served in cups	–		X	$E=1020\ (T \leqq 1500)$ $E=0.293T+580\ (1500<T)$

1. Vb = Adjusted internal volume in litres (a numeric value determined by first multiplying the actual internal volume of the hot storage compartment by 40, which is divided by 10, and then by adding the result to the actual internal volume of the cold storage compartment)

2. T = Adjusted heat capacity in units of kJ (a numeric value obtained by totalling the hot-water tank capacity multiplied by 80, the cold-water tank capacity multiplied by 15, and the ice storage capacity multiplied by 95 and then divided by 0.917, and then multiplying the total sum by 4.19).

Reported and estimated impacts Top Runner requirements

In the case of vending machines for canned/bottled beverages METI reports that their efficiency was improved by about 37.3% over the FY2000 level by the target year (FY 2005). METI further projected (in 2010) that for all vending machines: efficiency is expected to be improved by about 33.9% over the FY 2005 level by the target year (FY 2012).

Mexico

Mexico is not thought to have any energy efficiency requirements for vending machines.

South Africa

South Africa is not thought to have any energy efficiency requirements for vending machines.

USA

The USA has federal level MEPS and Energy Star labelling requirements for vending machines as set out below.

MEPS

Refrigerated bottled or canned beverage vending machines covered under this regulation fall into two classes:

- Class A – a refrigerated bottled or canned beverage vending machine that is fully cooled, and is not a combination machine.
- Class B – any refrigerated bottled or canned beverage vending machine not considered to be Class A, and is not a combination vending machine.

Refrigerated bottled or canned beverage vending machines manufactured on or after August 31, 2012 and distributed in commerce, as defined by 42 U.S.C. 6291(16), must meet the energy conservation standards specified in the Code of Federal Regulations, 10 CFR 431.296[24].

Table 60. US minimum energy performance requirements for refrigerated bottled or canned beverage vending machines

Equipment Class	Maximum daily energy consumption (kilowatt hours per day)*
Class A – a refrigerated bottled or canned beverage vending machine that is fully cooled, and is not a combination vending machine	MDEC = 0.055 x V + 2.56
Class B – a refrigerated bottled or canned beverage vending machine not considered to be Class A, and is not a combination vending machine	MDEC = 0.073 x V + 3.16
Combination Vending Machines – a refrigerated bottled or canned beverage machine that also has non-refrigerated volumes for the purpose of vending other, non-“sealed beverage” merchandise	[RESERVED]

* when measured at the 75 °F ± 2 °F and 45 ± 5% RH condition, V = Total Refrigerated Volume

Voluntary energy labelling

The old voluntary Energy Star specifications for vending machines which were in place up until 013 are set out in the text box below.

Energy Star Tier II Requirements New and Rebuilt Machines — effective July 1, 2007

Energy:
Y = 0.45 [8.66 + (0.009 x C)]
Where:
Y = 24 hr energy consumption (kWh/day) after the machine has stabilized
C = vendible capacity (number of 12 oz. cans)

Low Power Mode Requirement:
The machine shall be capable of operating in at least one of the low power mode states described below:
1. Lighting low power state — lights off for an extended period of time.
2. Refrigeration low power state — the average beverage temperature is allowed to rise above 40°F for an extended period of time.
3. Whole machine low power state — the lights are off and the refrigeration operates in its low power state.

It is interesting to note that these specifications are based on the number of delivered cans (vendible capacity) whereas the Federal MEPS are expressed in terms of the total refrigerated volume;

[24] http://www.gpo.gov/fdsys/pkg/CFR-2010-title10-vol3/pdf/CFR-2010-title10-vol3-sec431-296.pdf

however, this has been changed in the new specifications set out below. In addition the Energy Star eligibility specifications require the use of an Energy Star low power mode, which applies to lighting and to refrigeration. It would seem apparent that the “refrigeration low power state” cannot be applied to class A machines that also sell chilled snacks, as snacks must always be kept at the correct temperature.

From March 2013 Energy Star requirements have been amended to be as follows:

A. Maximum Daily Energy Consumption (MDEC): To qualify for ENERGY STAR, refrigerated beverage vending machines shall consume equal to or less than the MDEC values, in kWh/day, obtained using the equations below:

a. Class A – New and Rebuilt Machines: 0.0523V + 2.432
b. Class B – New and Rebuilt Machines: 0.0657V + 2.844

Where, V = the refrigerated volume (ft^3) of the refrigerated bottled or canned beverage vending machine, as measured by the American National Standards Institute (ANSI)/Association of Home Appliance Manufacturers (AHAM) HRF–1–2004, ‘‘Energy, Performance and Capacity of Household Refrigerators, Refrigerator-Freezers and Freezers.’’ Measurement of refrigerated volume must be in accordance with the methodology specified in Section 5.2, Total Refrigerated Volume (excluding subsections 5.2.2.2 through 5.2.2.4), of ANSI/AHAM HRF–1–2004[25].

B. Low Power Mode: In addition to meeting the 24-hour energy consumption requirements in Section 3A, qualifying models shall come equipped with hard wired controls and/or software capable of placing the machine into a low power mode during periods of extended inactivity while still connected to its power source to facilitate the saving of additional energy, where appropriate.

a. The machine shall be capable of operating in at least one of the low power mode states described below:

1. Lighting low power state – lights off for an extended period of time.

2. Refrigeration low power state – the average beverage temperature is allowed to rise to 40°F or higher for an extended period of time.

3. Whole machine low power state – the lights are off and the refrigeration operates in its low power state.

b. Machine shall be capable of returning itself back to its normal operating conditions at the conclusion of the inactivity period.

c. The low power mode-related controls/software shall be capable of on-site adjustment by the vending operator or machine owner unless the low power controlling device is already pre-programmed when installed into the machine.

While only one of the above low power mode states is required, EPA encourages new machine manufacturers to continue to include all of the low power mode options in equipment designs and partners that are rebuilding machines to seek out new technologies that might help to achieve this goal as well.

Alternative refrigerant use

Hydrocarbon R441a may be sold in new vending machines as of May 2012 as stated in a USEPA letter. The Agency has also recently indicated that a draft rule on the use of CO2 in vending

[25] 10 CFR Part 431.294.

machines is in the works before the end of the year. The letter also states that R441a may be sold “in stand-alone refrigerators and freezers in retail food refrigeration in the US as of June 27, 2012;” the approval also includes use in stand-alone refrigerated display cases.

Following the determination of the submission as “complete,” the US EPA will initiate the rule-making procedure, with R441a expected to be listed on the Federal Register within the next 24 months.

Vending machines: In the summer of 2012, the US EPA also found complete another submission requesting SNAP approval for the use of hydrocarbon refrigerant R441a in new vending machines by the US Environmental Protection Agency (EPA). R441a may now be sold in new vending machines as of May 23, 2012. Again, the rule listing R441a on the Federal Register is expected within the next 24 months.

3.4 Energy efficiency of product markets

Data sets on vending machine energy performance are available for:

- US data are available from both the Energy Star programme (93 models) and from the California Energy Commission website (49 models). These databases were analysed in the IEA-4E mapping document for US vending machines. Data on US vending machines and their distribution by efficiency are also available in the US TSD (2009)
- Canadian data are available from the federal government database (39 models).
- Australian data were collected in the framework of the IEA-4E mapping project on vending machines (IEA 2012e) (38 models). These data are derived from research reports commissioned by the Australian Government covering 2002 and 2004, completed by a number of independent test reports
- European data were collected in the framework of the IEA-4E mapping project on vending machines (IEA 2012f) (21 models)
- The energy performance of Japanese vending machines is discussed and analysed in METI (2012) but no databases were available for use in this project

These data sets were analysed to determine the default efficiency distributions used in the macro level energy consumption scenarios presented in section 3.8.

3.5 Stocks and sales

There are various sources of information on stocks and sales of vending machines for the same markets as for which energy data are available (see above).

As with reach-in coolers, data on the stocks and sales of vending machines are challenging to come by, however, detailed time-series have been acquired for the USA (USTSD 2009) and for Japan. Data on the stock of units on the Australian market are available from the IEA 4E (2012) report and also some reported values for the EU market.

In the case of the EU, the European Vending Association also supplied some stock estimates and some information on the size of the Brazilian vending machine market.

In the case of other markets, sales value data are available from a Freedonia market report[26] that was extrapolated into unit sales data using the same technique described in section 2.6 for reach-in coolers. For this exercise it was assumed that the average price of a vending machine was as indicated in the US TSD for class A and class B machines respectively.

[26] http://www.mzweb.com.br/metalfrio2008/web/conteudo_en.asp?idioma=1&conta=44&tipo=19837#3

The resulting estimates of unit volume sales from 1999 to 2009 are shown in Table 61 and the stock values derived from an extended version of this data run through a stock model are shown in Table 62. Some aspects of these data stand out and are worthy of comment:

Table 61. Estimated sales (thousands of units) of refrigerated vending machines worldwide 1999–2009 (derived from numerous sources including Freedonia, US TSD, EU EVA and METI)

	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009
United States	477	338	300	250	200	200	200	125	90	90	90
Canada	11	12	12	12	13	13	13	13	13	14	14
Mexico	35	36	38	40	42	44	43	42	42	41	40
Western Europe	176	181	186	192	197	203	206	208	211	134	135
Russia	11	12	13	13	14	15	16	17	18	19	20
Other Eastern European countries	19	19	20	20	21	22	23	24	25	26	27
Japan	377	364	352	341	329	318	312	307	301	296	291
China	8	10	13	16	20	26	29	33	38	43	48
India	7	8	8	9	10	10	11	12	13	14	16
Other Asian countries	61	63	66	68	71	74	79	83	88	93	98
Brazil	16	16	17	17	17	18	19	20	22	23	25
Rest of Latin America	16	16	17	17	18	18	19	20	21	22	23
Turkey	5	5	5	5	5	6	6	6	7	7	8
Rest of Africa/Middle East	20	21	21	21	22	22	23	25	26	28	29
Total	1238	1102	1067	1023	980	990	1000	936	914	848	863

Japan is comfortably the world's largest market for vending machines and the stock of refrigerated vending machines was 2.85 million units in 2009.

Sales in the USA peaked in 1999 and underwent a sharp decline to 2009. This phenomenon is not explained in the US DOE TSD (the source of the data) but the dramatic fall in sales could be a combination of transitioning from a new to a replacement market combined with the economic downturn in 2008/9.

Sales in the EU and Japan also declined from 1999 to 2009 but not as dramatically as in the USA. This presumably reflects the general economic climate at that time.

Sales in all other economies would seem to be much less than in the EU, Japan and the USA although growth rates have been greatest in the emerging economies. This suggests that even more so than for reach-in coolers, sales volumes are strongly related to local cultural factors, and the cost of labour (given that automated vending competes with direct human to human sales), as much as they are to the overall size of the economy.

Table 62. Estimated stock (thousands of units) of refrigerated vending machines worldwide 1999−2009 (derived from numerous sources)

	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009
United States	2699	2827	2914	2947	2895	2797	2681	2462	2180	1793	1545
Canada	90	93	96	99	101	104	107	110	112	115	117
Mexico	258	271	285	299	314	329	343	354	362	368	372
Western Europe	1415	1456	1499	1543	1588	1634	1679	1721	1761	1719	1673
Russia	82	86	92	97	103	109	115	122	129	136	144
Other Eastern European countries	152	156	161	165	170	175	180	186	192	200	208
Japan	3262	3278	3279	3264	3234	3190	3137	3074	3002	2921	2847
China	32	41	52	66	84	107	133	161	193	228	267
India	46	50	54	59	64	69	75	81	88	95	104
Other Asian countries	465	484	505	526	548	571	596	623	653	685	719
Brazil	133	135	138	141	144	147	151	156	162	170	178
Rest of Latin America	131	134	137	141	144	148	152	157	162	168	175
Turkey	37	38	40	41	43	44	46	48	50	52	55
Rest of Africa/Middle East	172	175	178	181	184	187	191	196	202	210	218
Total	8973	9226	9428	9568	9616	9613	9586	9452	9250	8860	8622

There is only a limited amount of data available on the share of refrigerated vending machines by product type: for Japan (METI 2012), the USA (USTSD 2009) and the EU (EVA 2013, JRC 2013).

For the purposes of the energy stock modelling analysis reported in section 3.8 the share of product sub-types assumed in each of the other economies was estimated as follows:

Brazil, India, RSA – assumed to match product sub-type shares in the EU

Australia, Mexico – assumed to match product sub-type shares in the USA

China – assumed to match product sub-type shares in Japan

3.6 Benchmarking of product efficiency: comparing across different test procedures

A vending machine energy performance data benchmarking analysis was recently completed by the IEA 4E Implementing Agreement, and is reported in the IEA-4E benchmarking document on cold vending machines (IEA 2012g). This report is based on a meta-analysis of four underlying mapping reports on individual economies (the USA, Canada, the EU and Australia).

The IEA 4E mapping report suggests that the interior temperature should where possible (i.e. when temperature data are available) be normalised to 4.4°C, by applying a 3% energy consumption decrease per °C higher storage temperature. The ambient temperature at ASHRAE 32.1 outdoor test conditions is 32.2 °C (at 65% R.H.). The IEA-4E mapping report suggests that energy consumption tested at other ambient temperatures be adjusted at a rate of 3% per °C difference to bring the results into line with the values expected at a 4.4 °C ambient test condition.

Comparison of the energy performance of vending machines measured under EVA-EMP or ASHRAE 32.1 is nominally possible after this kind of normalisation.

The results following this kind of adjustment are shown in Table 63, and compare the adjusted average energy consumption of the products in each regional database under a common but arbitrary efficiency metric of the energy used per can stored normalised to the storage of 300 cans. Superficially these results indicate that the EU products are less efficient than the products in the Australian or US Energy Star dataset but this appears to be largely explicable through differences in service (functionality) and may therefore be explained through insufficient product categorisation in the IEA 4E benchmarking analysis.

Table 63. Average normalised energy consumption per 300 cans for cold vending machines at outdoor temperature conditions under ASHRAE 32.1 and at an average product temperature of 4.4 °C

Data set	No .of models	Average consumption per 300 cans (kWh/day)
USA Energy Star (2010) IEA-4E[1]	93	3.22
California EC (2010) IEA-4E	42	5.28
Canada federal database 2010 IEA-4E	39	4.89
Australia 2009, IEA-4E mapping report	38	4.02
EU beverage 2011, IEA-4E mapping report	21	5.63

[1] Note the Energy Star database only covers the higher efficiency end of the US market

EU data in the IEA Benchmarking study

The IEA 4E vending machines benchmarking study gives the impression that EU vending machines have a higher energy consumption than other vending machines. In the summary it is noted that "The average European machine is 25% smaller than the Australian one but has only 4 % lower consumption per day."

Results presented in the US DOE's energy engineering analysis (USTSD 2009), in which base case vending machines of varying size have been modelled[27], indicate that when machines are 25 % smaller, the energy consumption would on average be 6.3 % lower. The benchmark study finds a difference of only 4 %, which would indicate that the EU models actually have a 2.3 % higher energy consumption than their Australian counterparts. However, the prevalence of the type of vending machine sold in each market is likely to have a greater impact. The EU dataset contains relatively more class A models than the other data sets and class A models have a higher energy consumption on average than class B models, as follows:

- under the US TSD (2009) energy engineering analysis the base case consumption class A (medium sized) vending machines was 17.4% higher than for class B (medium sized machine)
- in the California Energy Commission dataset the average energy consumption of class A vending machines is 18.4% higher than for class B machines

Thus, a dataset containing 62 % class A vending machines (such as the EU 2010 dataset) versus a dataset containing only 15 % class A vending machines (Australian dataset) would show an 8 % higher energy consumption.

[27] The DOE engineering analysis considered Class A vending machines of three different sizes: small (300 cans), medium (400 cans) and large (500 cans), as well as class B machines of three different sizes: small (450 cans), medium (650 cans) and large (800 cans).

Taking both the difference in size and the difference in class A / class B distributions into account, it could be concluded that the EU dataset is 8 % - 2.3 % = 5.7 % more efficient than the Australian dataset.

There is also a difference between the EU dataset and the Canadian and California datasets, of 9 % and 11 % respectively. The percentage of class A vending machines is unknown for the Canadian dataset; however, the California dataset contains 38 % class A machines and 62% class B machines, thus a correction of 4% can be applied, which makes the actual difference with the EU dataset smaller (7 % instead of 11 %). Making this adjustment (and assuming the Canadian dataset has the same preponderance of class A and B machines as in California) leaves the conclusion that the California and Canadian data sets have an average energy efficiency of 7 % – 9 % higher than the EU dataset. This could be explained by the presence of minimum energy performance standards, Energy Star requirements and other incentives for energy efficient machines in the USA and Canada.

3.7 Life cycle cost energy engineering analysis for refrigerated vending machines

There have been various attempts in the literature to estimate the savings potentials achievable from deploying higher efficiency design options. Table 64 shows an analysis from the original EU Ecodesign Lot 12 study for spiral vending machines whereas Table 65 shows a much older US analysis by Arthur D. Little. The most useful analysis, however, is in the US TSD (2009) that was conducted in support of the most recent US energy efficiency standards rulemaking effort.

Table 64. Potential energy saving design options for a base case Spiral Vending Machine (TSD 2009)

	Improvement option	TEC savings compared to base case Spiral Vending Machine (%)	Increase of product cost compared to base case Spiral Vending Machine	Payback time (years)
Option 1	Anti-sweat heater location	18	30	0.58
Option 2	Vacuum insulated panels (VIPs)	6.5	25	1.34
Option 3	Compressor modulation (variable speed drive)	22	200	3.18

Table 65. Potential energy saving design options for a base case refrigerated vending machine in the USA (Arthur D. Little 1996)

Baseline Energy Usage 2763 kWh[1]

	Technology Option	End-User Cost Premium	Load Reduction (W)	Energy Reduction (kWh/yr)	Energy Reduction (%)	Simple Payback Period (yrs)		
						High Rate ($0.1834 kWh)	Medium Rate ($0.0782 kWh)	Medium-Low Rate ($0.0743 kWh)
1	Thicker Insulation	$54	17	150	5.4	2.0	4.6	4.8
2	PSC Evap Fan Motor	$36	35	305	11	0.6	1.5	1.6
3	ECM Evap. Fan Motor	$56	45	395	14	0.8	1.8	1.9
4	PSC Cond Fan Motor	$36	22	67	2.4	2.9	6.9	7.2
5	ECM Cond. Fan Motor	$56	29	87	3.1	3.5	8.2	8.7
6	High-Efficiency Compressor	$16	85	260	9	0.3	0.8	0.8
7	ECM Compressor Motor	$100	62	191	7	2.9	6.7	7.0
8	Variable Speed Compressor	$150	62	413	15	2.0	4.6	4.9
9	Lighting Improvement	$30	29	255	9.2	0.6	1.5	1.6
10	High-Efficiency Fan Blades	$2	14	92	3.3	0.1	0.3	0.3
11	Combination	$72	104	778	28	0.5	1.2	1.2

[1]This baseline is for a machine with standard output lighting. For a machine with high-output lighting, the baseline is 3165 kWh.

The US Department of Energy techno-economic energy engineering analysis (TSD 2009) considers the following technologies for improving the energy efficiency of vending machines:

- higher efficiency lighting
- higher efficiency lighting ballasts
- higher efficiency evaporator fan motors
- evaporator fan motor controllers
- higher efficiency evaporator fan blades (not considered in engineering analysis)
- improved evaporator design
- low-pressure differential evaporators (not considered in engineering analysis)
- insulation increases or improvements
- defrost mechanism (not considered in engineering analysis)
- improved glass pack (for Class A machines only)
- higher efficiency condenser fan motors
- higher efficiency condenser fan blades (not considered in engineering analysis)
- improved condenser design

- higher efficiency compressors

For these options, the USDOE performed a detailed engineering analysis for both class A (glass front) and class B (opaque front) vending machines, with three size options per class (small, medium, large). The characteristics of the base case appliances considered in this analysis are presented in the first three rows of data in Table 66.

Table 66. Characteristics of base case refrigerated vending machines considered in the US TSD (2009)

DOE 2009 Basecase	Fully refrigerated (glass front)			Zone refrigerated, opaque		
Class – size	A-small	A-med	A-large	B=small	B-med	B-large
Energy Consumption (kWh/day, 75 ^{0}F)	6.10	6.53	6.75	4.96	5.56	5.85
Refrigerated Volume (ft^3)	17	22	34	17	22	26
Capacity (12 oz. cans)	300	400	500	450	650	800
Energy Star Tier 2 (kWh/d)	5.11	5.52	5.92	5.72	6.53	7.14
Energy Star '2013 (kWh/d)	3.32	3.58	4.21	3.96	4.29	4.55

*) DOE base cases were designed (in consumption) to fulfil the then Energy Star Tier 1 requirements, which were 22 % above Tier 2 energy consumption requirements.

From the LCC results of the DOE engineering analysis, the savings percentages for the different design options can be calculated and shown in Table 67. The savings percentages shown in this table have been calculated for medium size machines (except for the option of evaporator fan control, which was already present in the medium size base case model but not in the small size units).

Table 67. Potential energy saving design options for refrigerated vending machines in the USA compared to a base case vending machine (US TSD 2009)

Design option	Saving in class A	Saving in class B
Evaporator fan control	7.0 %	-
High performance evaporator coil	8.6 %	-
T8 lighting -> Super T8 lighting	2.7 %	-
High efficiency compressor	1.9 %	1.5 %
ECM evaporator fan motor	3.3 %	6.5 %
Super T8 lighting -> LED lighting	24 %	10.6 %
High performance condenser coil	5.7 %	4.6 %
Add 1/8 inch of insulation	3.0 %	2.5 %
ECM condenser fan motor	1.0 %	0.8 %
Super-enhanced doors (glass)	7.1 %	-
Aerogel insulation	2.6 %	2.4 %

The requirement in the test standards used in the rulemaking that vending machines must be tested under factory settings and not using adjustable user settings will have impeded consideration of energy saving design options that power down the machines during night periods or whenever consumers are not present. However, the advent of cheap electronics and improved sensors is opening new opportunities for automatic (low energy) response to such factors. Thus there is likely to be a considerable potential for cost-effective energy saving using such technologies in reality.

Also, steady state testing, as prescribed in the standards does not provide any advantage for variable speed compressors that would have energy benefits in real-world non-steady ambient temperature and operating conditions.

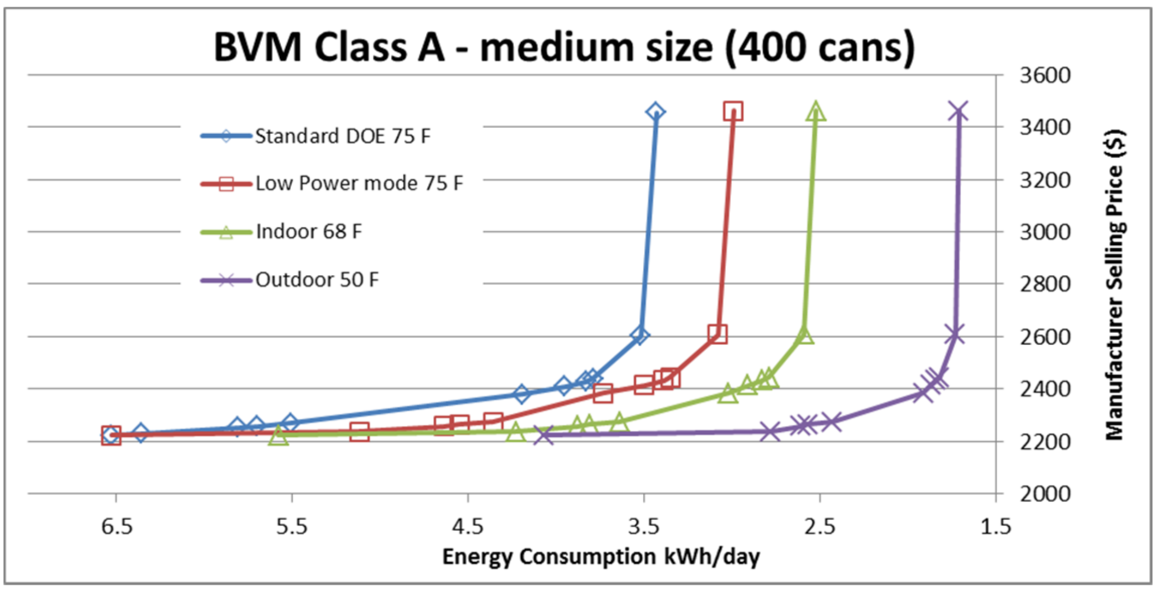
Revised Beverage Vending Machine Engineering Analysis

The original engineering analysis on beverage vending machines was performed by USDOE in 2009, and is documented in the USDOE technical support document (chapter 5). The present study uses the original USDOE spread-sheet, but revises the 2009 engineering analysis to take account of a number of issues. For class A machines, the order of the first two design options has been changed (improved lighting T8S instead of T8, and larger evaporator) for practical reasons.

The most important design option revision is the addition of a “Low Power mode” for lighting[28], as required by the Energy Star programme. This low power lighting mode is assumed to be active for 12 hours out of 24 hours, at an additional cost of US$5.

Another important revision is to alter the ambient temperature to better reflect real usage conditions. The original USDOE engineering analysis is performed at indoor ambient test temperature conditions of 75 ^{o}F. In the revised analysis two temperature levels are assumed: 20 ^{o}C (68 ^{o}F) as representative for an indoor condition (22 ^{o}C day time, 18 ^{o}C night time) and 10.1 ^{o}C as representative of a relatively cool outdoor climate (Chicago yearly average temperature).

Figure 40. Revised engineering analysis results for class A vending machines compared to DOE standard at 75 ^{O}F*



*Each point in the graph represents a design option. On the different curves, the order of applying the design options is not changed. The first design option is the application of a low power mode. (except in the DOE standard, where the first design option is T8S lighting instead of T8 lighting)

A final amendment revision concerns the assumed energy price, where in the revised analysis the influence of using a 2009 average European service sector energy price of US$0.18/kWh is considered as well as the original price used by the USDOE of US$0.08/kWh). The results of changing the energy price are straightforward; the order of design options is not changed, but

[28] A low power mode for refrigeration is not considered, as it is considerably less effective than the lighting low power mode, and also because it could infringe on food conservation requirements when (perishable) snacks are sold from the machine.

merely the (simple) payback time is changed for each option, Table 68. Note, that these payback periods do not factor in the impact that increased product price may have on the installation costs but this is factored in to the life cycle cost analysis presented later on in this section.

Table 68. Class A vending machine payback periods for each higher efficiency design option

Payback times EU	Option										
1 kWh = $ 0.18	1	2	3	4	5	6	7	8	9	10	11
Standard DOE 75 °F	0.2	0.6	0.8	0.9	0.9	1.3	1.9	2.5	4.4	9.3	146.8
Low Power Mode 75 °	0.2	0.7	0.6	0.9	0.9	1.3	1.9	2.5	4.4	9.3	146.8
Indoor 68 °F	0.2	0.2	1.0	1.3	1.0	2.7	4.2	3.7	4.4	12.6	188.7
Outdoor 50 °F	0.2	0.2	2.0	2.3	1.3	3.3	11.6	9.9	8.8	28.0	660.5
Payback times USA	Option										
1 kWh = $ 0.08	1	2	3	4	5	6	7	8	9	10	11
Standard DOE 75 °F	0.4	1.3	1.7	1.9	2.1	2.8	4.3	5.5	9.8	20.7	324.9
Low Power Mode 75 °	0.4	1.6	1.3	1.9	2.1	2.8	4.3	5.5	9.8	20.7	324.9
Indoor 68 °F	0.5	0.3	2.1	3.0	2.3	6.1	9.3	8.2	9.8	27.9	417.8
Outdoor 50 °F	0.5	0.4	4.3	5.2	2.8	6.1	25.7	21.9	19.5	62.0	1462.2

Option 1: Base case BVM, class A medium size (400 cans).

Option 2: T8S lighting instead of T8 lighting (USDOE) or T8S & Low Power Lighting Mode

Option 3: Larger evaporator

Option 4: High efficiency compressor

Option 5: ECM evaporator fan motors

Option 6: LED lighting

Option 7: Larger condenser

Option 8: increased insulation

Option 9: ECM condenser fan motors

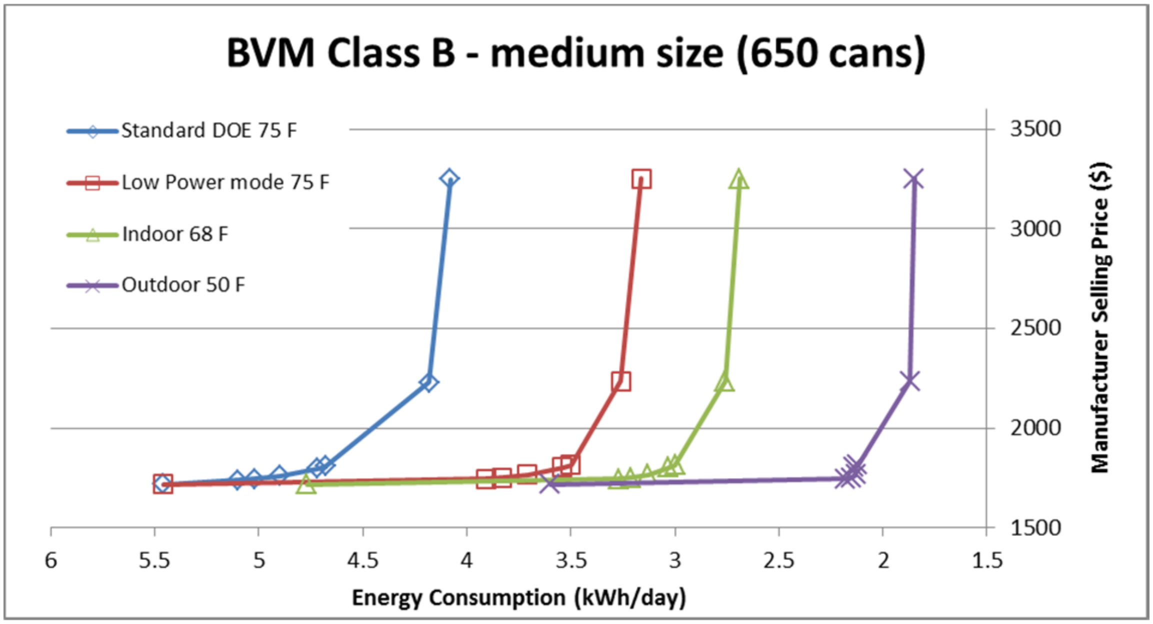
Option 10: Improved glass door

Option 11: Vacuum insulation

Options 4-11: same as in original USDOE engineering analysis

The same exercise was conducted for class B beverage vending machines– medium size (650 cans capacity), with similar results (Figure 41 and Table 67).

Figure 41. Revised engineering analysis results for class B vending machines compared to DOE standard at 75 ^{0}F*



*Each point in the graph represents a design option. On the different curves, the order of applying the design options is not changed. The first design option is the application of a low power mode. (except in the DOE standard, where the first design option is T8S lighting instead of T8 lighting).

The impact of changing the energy price is shown in Table 69, and again only influences the payback period, not the order of application of the design options. Once again it should be noted that these payback periods do not factor in the impact that increased product price may have on the installation costs although this is factored in to the life cycle cost analysis presented later on in this section.

Table 69. Class B vending machine payback periods for each higher efficiency design option

Payback times EU	Option							
1 kWh = $ 0.18	1	2	3	4	5	6	7	8
Standard DOE 75 ºF	0.1	1.0	1.0	1.9	2.4	4.4	13.0	157.6
Low Power Mode 75 ⁰	0.1	1.0	1.0	2.0	3.0	4.4	13.0	157.6
Indoor 68 ^{0}F	0.1	0.3	1.3	3.1	5.5	5.9	27.1	225.2
Outdoor 50 ^{0}F	0.1	0.3	2.6	12.2	-54.8	8.8	26.0	788.2
Payback times USA	Option							
1 kWh = $ 0.08	1	2	3	4	5	6	7	8
Standard DOE 75 ^{0}F	0.3	2.2	2.2	4.2	5.3	9.8	28.8	349.0
Low Power Mode 75 ^{0}	0.3	2.2	2.2	4.5	6.7	9.8	28.8	349.0
Indoor 68 ^{0}F	0.3	0.6	2.9	6.8	12.1	13.0	60.0	498.5
Outdoor 50 ^{0}F	0.3	0.7	5.9	27.1	-121.3	19.5	57.6	1744.8

Option 1: Base case BVM, class B medium size (650 cans).

Option 2: ECM Evaporator Fan Motors (USDOE) or ECM Motors & Low Power Lighting Mode

Option 3: High efficiency compressor

Option 4: Increased insulation

Option 5: Larger condenser

Option 6: ECM condenser fan motors

Option 7: LED lighting

Option 8: Vacuum insulation

Options 3 - 8: same as in original USDOE engineering analysis

Life cycle cost curves

Life cycle cost curves can be produced, for both class A and class B vending machines, from the revised engineering analysis results, Figures 42 to 45. The assumed mark-up on manufacturer selling price, installation costs, yearly service and maintenance costs and average life of beverage vending machines as the same as in the original USDOE TSD. Two levels of energy costs are considered: US$ 0.08/kWh (to illustrate the US case) and US$ 0.18/kWh (to illustrate the EU case).

Figure 42: LCC curves for BVM class A at an energy price of $ 0.08 / kWh

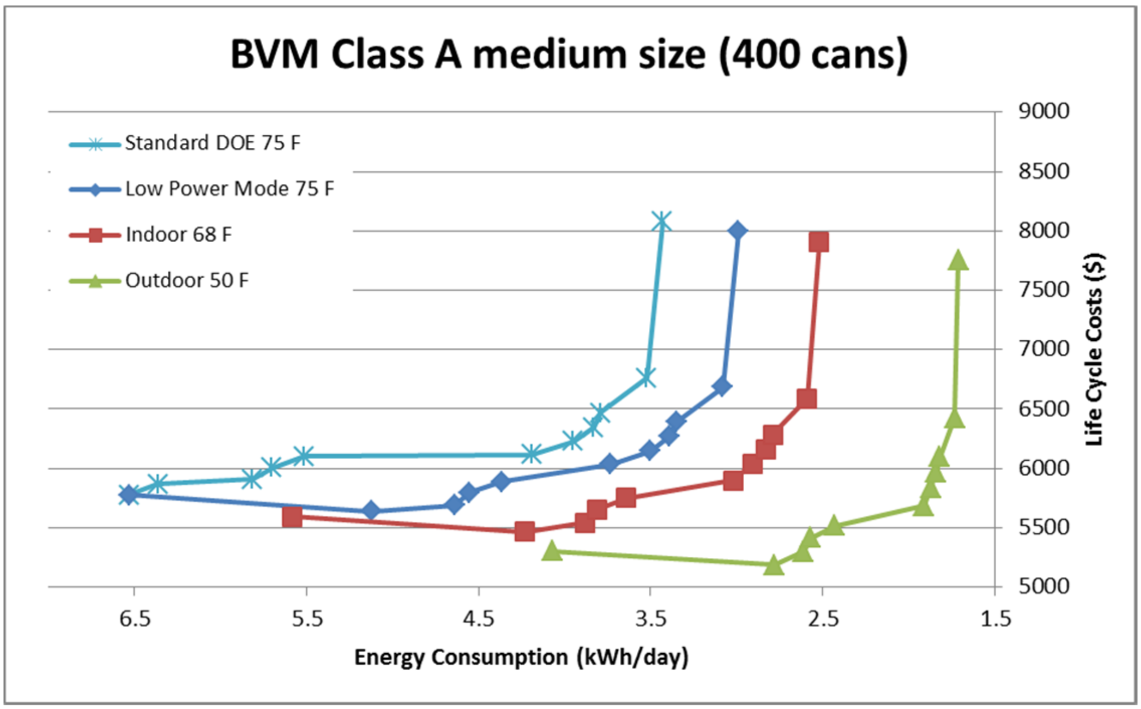


Figure 13: LCC for BVM class A at an energy price of $ 0.18 / kWh

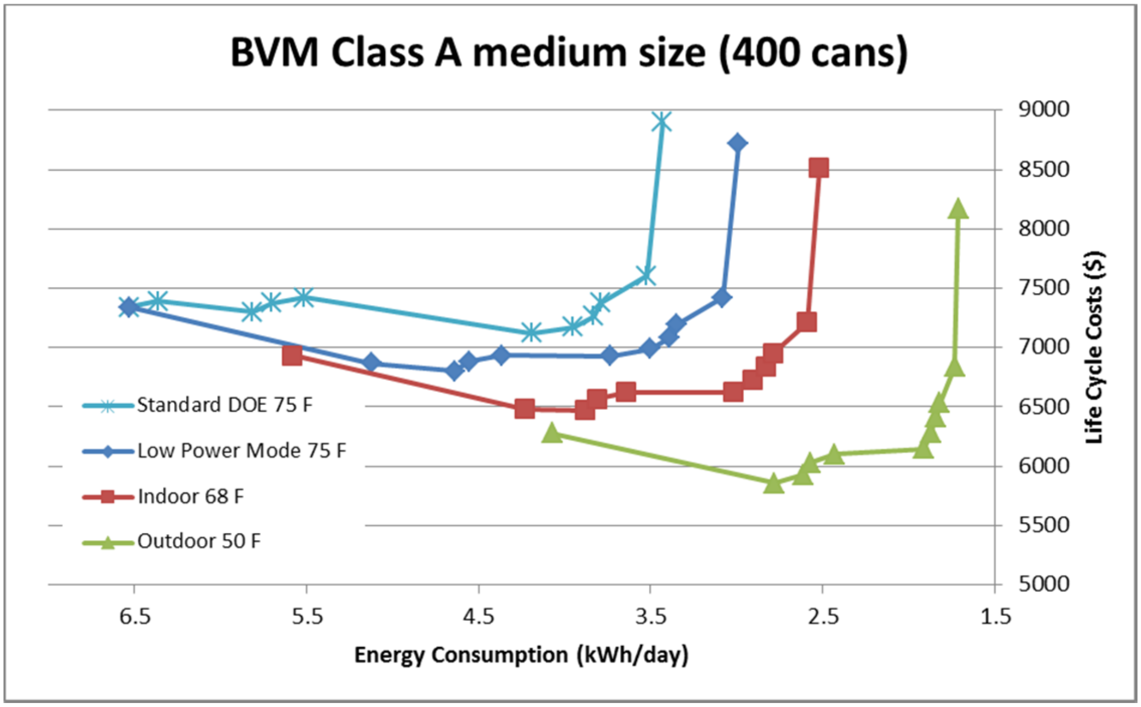


Figure 44: LCC for BVM class B at an energy price of $ 0.08 / kWh

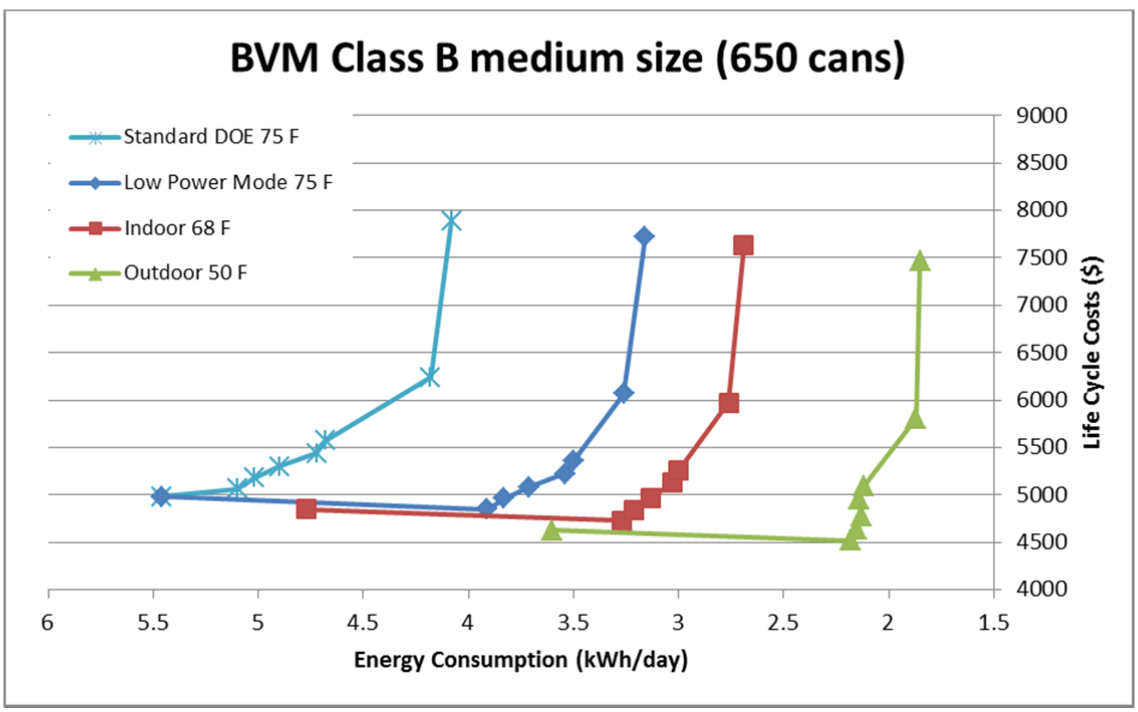
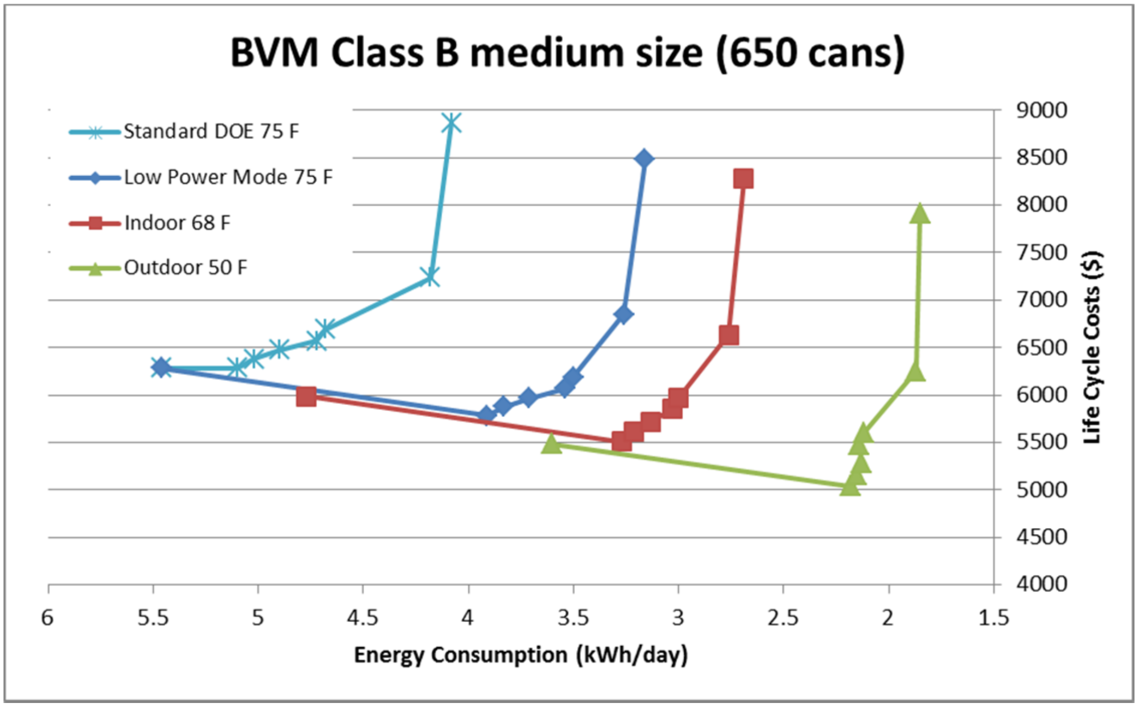


Figure 45: LCC for BVM class B at an energy price of $ 0.18 / kWh



The life cycle cost minimum occurs for the first option (the low power lighting mode) for all the cases of class B machine considered.

For class A machines – except in the original USDOE analysis – the LCC minimum either occurs for the low power lighting mode option or at the option following that (the high efficiency compressor). The LCC minimum is more pronounced at higher energy prices and lower temperatures.

3.8 Potential for energy savings at the macro scale

The total energy consumption of refrigerated vending machines was estimated and forecast for all of the targeted economies for this analysis under three scenarios as follows:

- Business As Usual Scenario – this assumes no new policies to promote energy efficiency for refrigerated vending machines other than those already implemented
- Least Life Cycle Cost Scenario – this assumes that from 2014 onwards all new products sold are at the energy efficiency level associated with the least life cycle cost from an end-users perspective
- Maximum Technical Efficiency Scenario – this assumes all new products sold from 2014 onwards are at the maximum technically achievable efficiency today, i.e. in 2013

The total forecast energy consumption per economy under the Business as Usual Scenario is shown in Table 70 and the total energy savings compared under the Least Life Cycle Cost Scenario and Maximum Technical Efficiency Scenario respectively compared to the Business as Usual case are shown in Tables 71 and 72.

Table 70. Estimated electricity consumption of refrigerated vending machines in coolers under the Business as Usual Scenario

	Electricity consumption (TWh/year)					
	2009	2013	2020	2025	2030	2035
USA	2.5	2.1	2.7	2.8	2.9	3.1
MEXICO	1.2	1.2	1.5	1.7	1.9	2.1
EU	4.5	4.1	4.0	4.4	4.7	4.9
JAPAN	6.4	6.0	6.1	6.4	6.7	7.1
CHINA	0.9	1.6	3.1	4.0	5.0	6.1
INDIA	0.3	0.5	0.8	1.2	1.7	2.3
BRAZIL	0.6	0.7	0.8	0.9	1.0	1.1
RSA	0.1	0.1	0.1	0.1	0.2	0.2
AUSTRALIA	0.5	0.5	0.6	0.6	0.6	0.6
TOTAL	**16.9**	**16.7**	**19.8**	**22.1**	**24.7**	**27.4**

Table 71. Estimated savings in electricity consumption of refrigerated vending machines under the Least Life Cycle Cost Scenario compared with the Business as Usual Scenario

	Electricity consumption (TWh/year)					
	2009	2013	2020	2025	2030	2035
USA	0.0	0.0	0.8	1.2	1.2	1.3
MEXICO	0.0	0.0	0.5	0.9	1.0	1.0
EU	0.0	0.0	1.0	1.6	1.7	1.8
JAPAN	0.0	0.0	1.3	2.0	2.2	2.3
CHINA	0.0	0.0	1.1	2.0	2.4	3.0
INDIA	0.0	0.0	0.3	0.6	0.8	1.1
BRAZIL	0.0	0.0	0.3	0.5	0.5	0.6
RSA	0.0	0.0	0.0	0.1	0.1	0.1
AUSTRALIA	0.0	0.0	0.1	0.2	0.2	0.2
TOTAL	**0.0**	**0.0**	**5.5**	**9.0**	**10.1**	**11.4**

Table 72. Estimated savings in electricity consumption of refrigerated vending machines under the Maximum Technical Potential Scenario compared with the Business as Usual Scenario

	Electricity consumption (TWh/year)					
	2009	2013	2020	2025	2030	2035
USA	0.0	0.0	0.9	1.4	1.5	1.5
MEXICO	0.0	0.0	0.8	1.3	1.5	1.6
EU	0.0	0.0	1.9	3.0	3.1	3.3
JAPAN	0.0	0.0	2.6	4.1	4.3	4.5
CHINA	0.0	0.0	1.7	3.0	3.7	4.6
INDIA	0.0	0.0	0.5	0.9	1.3	1.7
BRAZIL	0.0	0.0	0.4	0.7	0.7	0.8
RSA	0.0	0.0	0.1	0.1	0.1	0.1
AUSTRALIA	0.0	0.0	0.2	0.3	0.3	0.3
TOTAL	**0.0**	**0.0**	**9.0**	**14.7**	**16.5**	**18.5**

For refrigerated vending machines, the Least Life Cycle Cost Scenario shows energy savings of 11.4 TWh (42%) and the Maximum Technical Potential Scenario shows energy savings of 18.5 TWh (67%) compared to Business As Usual.

Modelling and assumptions

Modelling these savings was done using a time-series stock model that was adapted from the model used to produce the US national impacts analysis in support of the most recent DOE rulemaking[29]. For each economy, sales data were used to generate stock data assuming an average 8 year product life span. In some cases sales value time series data was converted into unit sales time series data by using information on the typical unit price per product type (usually derived from US or EU data). Whenever possible the resulting stock values were corroborated against other available stock or unit sales data (this was the case for Japan, the USA, the EU, Brazil and Australia) and in these cases the stock/sales estimates from the sales value data were found to agree with the independent estimates within +/-15%. Although the independent stock size estimates were used in preference to the model projections in those markets where such data were available, the closeness of the results gives a certain degree of confidence in the projections made for those markets where such data were not available.

Projections of refrigerated vending machine stocks were then derived for class A and class B machines based on what was known about the relative sales shares of refrigerated vending machine types in each market. In several cases these data are not available (Brazil, China, India, Japan, Mexico, RSA) and hence was estimated by using the distribution of class A and class B machines in other economies as a proxy.

Energy consumption per refrigerated vending machine type was derived by first adjusting all test procedure energy consumption data to values that would be expected in situ (i.e. in the locations where the appliances are installed) by applying the ambient temperature correction functions explained in section 3.2. The consumption by product type was then adjusted for: a) any known differences in the average product size by economy from the US data, b) any known differences in efficiency by product type compared to the US average. Both of these sets of derived estimates have considerable uncertainties attached to them. Differences in average product size are calculated compared to the US model from the various data sources assembled in the study. Estimates of the

[29] http://www.regulations.gov/#!documentDetail;D=EERE-2006-STD-0125-0080

average difference in product efficiency are highly uncertain in many cases as the data sets used are patchy or incomplete. The uncertainty in all these factors could result in there being significant errors in the base case (business as usual) efficiency level and unit average energy consumption assumed in the Business as Usual Scenario.

For both the Least Life Cycle Cost scenario and the Maximum Technical Efficiency Scenario it is assumed that new products sold up to 2014 are at the Business As Usual Scenario efficiency level and that after 2014 they are at the efficiency associated with the Least Life Cycle Cost or the Maximum Technically Achievable level respectively. The analysis presented in section 3.7 is used to derive these values but in the case of the Least Life Cycle Cost scenario the efficiency level of LLCC varies by economy depending on the average electricity tariff (for the sake of simplicity product costs are assumed to be the same as in the USA for all economies except the EU (where EU data were available and used) although adjusted for differences in average product size – thus variations in labour, transport and material costs are not considered and nor are variations in production/distribution margins and other local factors considered). For both the LLCC and Maximum Technical Efficiency Scenarios it is (conservatively) assumed that there is no ongoing learning effect i.e. that the incremental costs of more efficient products remain unchanged over time and that there is no long term improvement in the maximum efficiency level attainable. Neither of these assumptions is likely to be accurate as the incremental cost of efficiency will most likely decline over time and new technology will enable higher efficiency products to be produced.

The energy consumption under the business as usual scenario is shown in Figure 46, whereas Figures 47 and 48 shows the savings projected under the least life cycle cost and maximum technically achievable efficiency scenarios respectively.

Figure 46. Estimated energy consumption for Refrigerated Vending Machines in the nine SEAD economies under the Business as Usual scenario.

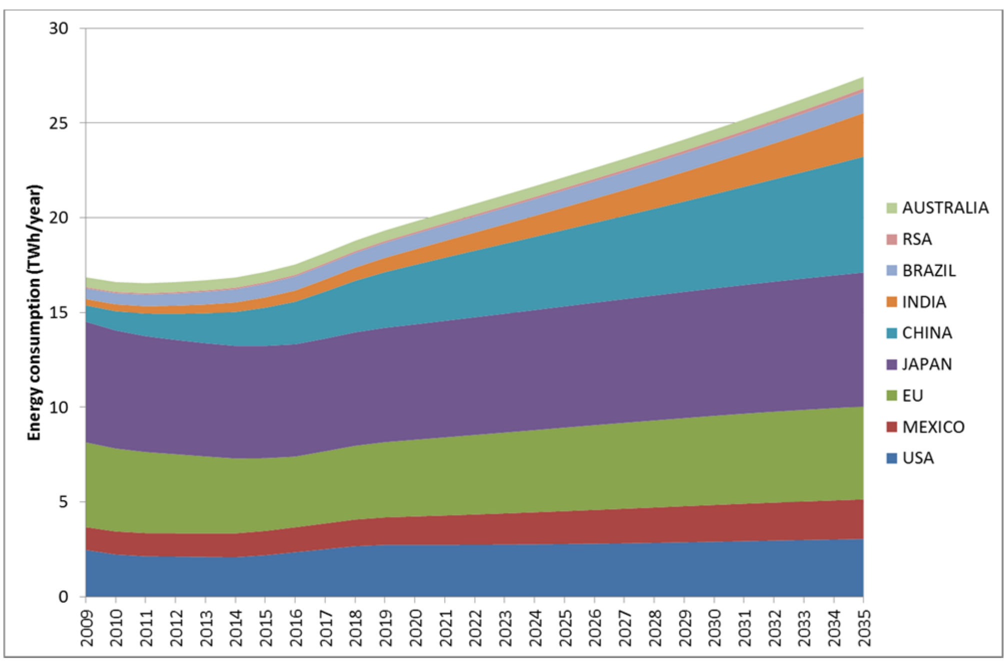


Figure 47. Estimated savings in energy consumption for Refrigerated Vending Machines in the nine SEAD economies under the Least Life Cycle Cost scenario compared to the Business as Usual Scenario.

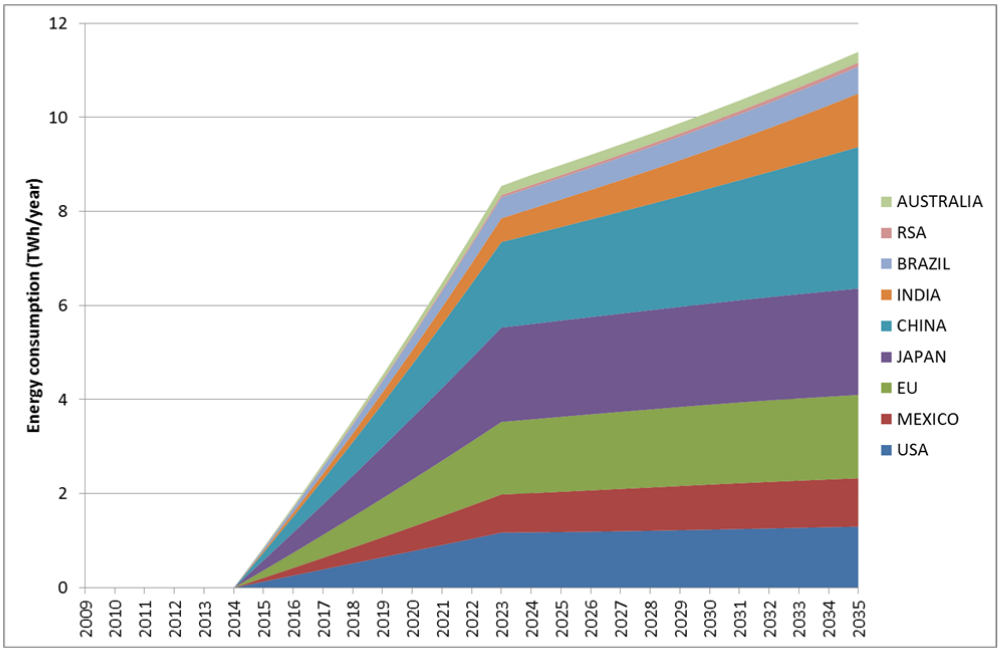
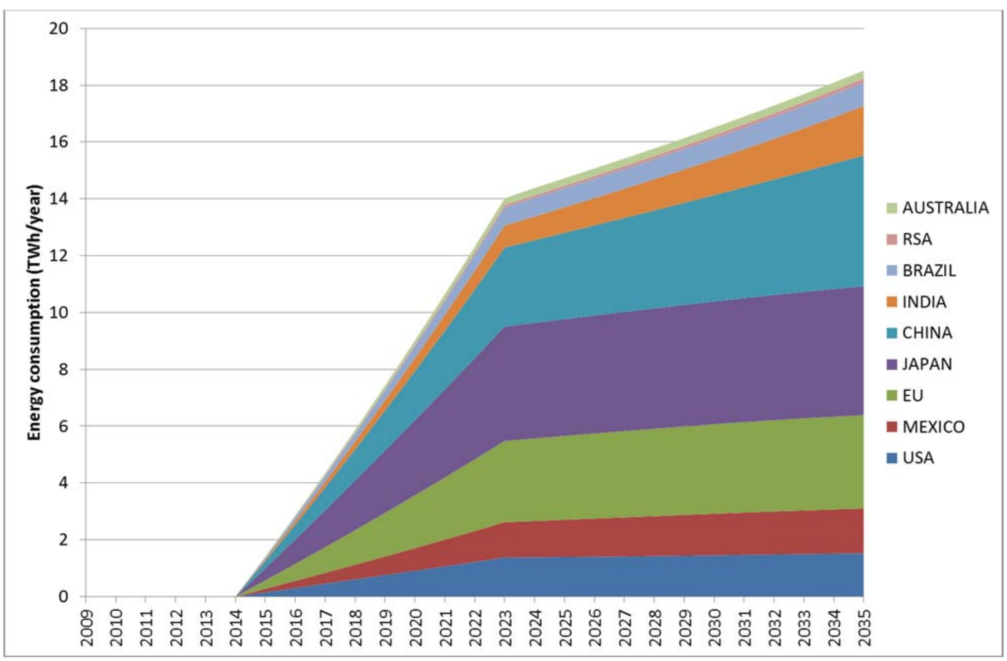


Figure 48. Estimated savings in energy consumption for Refrigerated Vending Machines in the nine SEAD economies under the Maximum Technical Efficiency scenario compared to the Business as Usual Scenario.



Appendix A: Life cycle costs for reach-in coolers as a function of energy efficiency

A.1 Horizontal Open freezer, remote (RHF4)

		Australia	Brazil	China	EU	India	Japan	Mexico	RSA	USA
Tariff (US$/kWh)		0.102	0.180	0.091	0.177	0.100	0.167	0.111	0.066	0.100
Life cycle costs per design option using the tariffs above										
ASHRAE test conditions										
Level	TEC/TDA	Australia	Brazil	China	EU	India	Japan	Mexico	RSA	USA
Baseline	8.98	$ 21,469	$ 29,117	$ 20,390	$ 28,833	$ 21,273	$ 27,842	$ 22,351	$ 17,939	$ 21,273
Permanent Split Cap. Evap. Fan Motor	8.66	$ 21,164	$ 28,540	$ 20,124	$ 28,266	$ 20,975	$ 27,311	$ 22,015	$ 17,759	$ 20,975
Brushless DC Evap. Fan Motor	8.26	$ 20,839	$ 27,874	$ 19,847	$ 27,612	$ 20,659	$ 26,701	$ 21,651	$ 17,592	$ 20,659
Enhanced-UA Evaporator Coil	7.82	$ 20,511	$ 27,169	$ 19,572	$ 26,922	$ 20,340	$ 26,060	$ 21,279	$ 17,438	$ 20,340
Additional 1/2" Insulation	7.71	$ 20,514	$ 27,084	$ 19,588	$ 26,840	$ 20,346	$ 25,989	$ 21,272	$ 17,482	$ 20,346
Min LCC		$ 20,511	$ 27,084	$ 19,572	$ 26,840	$ 20,340	$ 25,989	$ 21,272	$ 17,438	$ 20,340
EN-ISO test conditions										
Level	TEC/TDA	Australia	Brazil	China	EU	India	Japan	Mexico	RSA	USA
Baseline	9.28	$ 21,820	$ 29,727	$ 20,705	$ 29,433	$ 21,618	$ 28,409	$ 22,733	$ 18,171	$ 21,618
Permanent Split Cap. Evap. Fan Motor	8.96	$ 21,514	$ 29,148	$ 20,438	$ 28,864	$ 21,319	$ 27,876	$ 22,395	$ 17,991	$ 21,319
Brushless DC Evap. Fan Motor	8.56	$ 21,188	$ 28,479	$ 20,160	$ 28,208	$ 21,001	$ 27,263	$ 22,029	$ 17,823	$ 21,001
Enhanced-UA Evaporator Coil	8.10	$ 20,845	$ 27,741	$ 19,872	$ 27,484	$ 20,668	$ 26,591	$ 21,640	$ 17,662	$ 20,668
Additional 1/2" Insulation	7.99	$ 20,844	$ 27,650	$ 19,884	$ 27,397	$ 20,670	$ 26,515	$ 21,629	$ 17,703	$ 20,670
Min LCC		$ 20,844	$ 27,650	$ 19,872	$ 27,397	$ 20,668	$ 26,515	$ 21,629	$ 17,662	$ 20,668
In situ (store) conditions										
Level	TEC/TDA	Australia	Brazil	China	EU	India	Japan	Mexico	RSA	USA
Baseline	8.33	$ 20,719	$ 27,814	$ 19,718	$ 27,550	$ 20,537	$ 26,631	$ 21,537	$ 17,444	$ 20,537
Permanent Split Cap. Evap. Fan Motor	8.01	$ 20,416	$ 27,241	$ 19,454	$ 26,987	$ 20,241	$ 26,103	$ 21,204	$ 17,266	$ 20,241
Brushless DC Evap. Fan Motor	7.62	$ 20,095	$ 26,580	$ 19,180	$ 26,339	$ 19,928	$ 25,499	$ 20,843	$ 17,101	$ 19,928
Enhanced-UA Evaporator Coil	7.22	$ 19,802	$ 25,950	$ 18,935	$ 25,721	$ 19,644	$ 24,925	$ 20,511	$ 16,964	$ 19,644
Additional 1/2" Insulation	7.12	$ 19,815	$ 25,883	$ 18,960	$ 25,657	$ 19,660	$ 24,871	$ 20,515	$ 17,015	$ 19,660
Min LCC		$ 19,802	$ 25,883	$ 18,935	$ 25,657	$ 19,644	$ 24,871	$ 20,511	$ 16,964	$ 19,644

A.2 Horizontal Open freezer, integral (IHF4)

		Australia	Brazil	China	EU	India	Japan	Mexico	RSA	USA
Tariff (US$/kWh)		0.102	0.180	0.091	0.177	0.100	0.167	0.111	0.066	0.100
Life cycle costs per design option using the tariffs above										
ASHRAE test conditions										
Level	TEC/TDA	Australia	Brazil	China	EU	India	Japan	Mexico	RSA	USA
Baseline	34.70	$ 16,260	$ 23,969	$ 15,172	$ 23,683	$ 16,062	$ 22,684	$ 17,149	$ 12,701	$ 16,062
High-Eff. Reciprocating Compressor	32.64	$ 15,708	$ 22,961	$ 14,686	$ 22,691	$ 15,522	$ 21,752	$ 16,545	$ 12,361	$ 15,522
Permanent Split Cap. Evap. Fan Motor	32.30	$ 15,629	$ 22,807	$ 14,616	$ 22,540	$ 15,445	$ 21,611	$ 16,457	$ 12,316	$ 15,445
Brushless DC Evap. Fan Motor	31.89	$ 15,549	$ 22,635	$ 14,549	$ 22,372	$ 15,367	$ 21,454	$ 16,366	$ 12,278	$ 15,367
Enhanced-UA Evaporator Coil	30.18	$ 15,227	$ 21,933	$ 14,281	$ 21,684	$ 15,055	$ 20,815	$ 16,001	$ 12,132	$ 15,055
Permanent Split Cap. Cond. Fan Motor	30.07	$ 15,211	$ 21,892	$ 14,268	$ 21,643	$ 15,039	$ 20,778	$ 15,982	$ 12,127	$ 15,039
Enhanced-UA Condenser Coil	27.30	$ 14,979	$ 21,046	$ 14,124	$ 20,820	$ 14,824	$ 20,035	$ 15,679	$ 12,179	$ 14,824
Brushless DC Cond. Fan Motor	27.18	$ 14,985	$ 21,025	$ 14,133	$ 20,800	$ 14,830	$ 20,018	$ 15,682	$ 12,197	$ 14,830
Additional 1/2" Insulation	27.03	$ 15,097	$ 21,104	$ 14,250	$ 20,880	$ 14,943	$ 20,103	$ 15,790	$ 12,325	$ 14,943
Min LCC		$ 14,979	$ 21,025	$ 14,124	$ 20,800	$ 14,824	$ 20,018	$ 15,679	$ 12,127	$ 14,824
EN-ISO test conditions										
Level	TEC/TDA	Australia	Brazil	China	EU	India	Japan	Mexico	RSA	USA
Baseline	36.10	$ 16,750	$ 24,771	$ 15,619	$ 24,473	$ 16,544	$ 23,434	$ 17,675	$ 13,048	$ 16,544
High-Eff. Reciprocating Compressor	33.98	$ 16,186	$ 23,737	$ 15,121	$ 23,456	$ 15,993	$ 22,478	$ 17,058	$ 12,701	$ 15,993
Permanent Split Cap. Evap. Fan Motor	33.65	$ 16,107	$ 23,584	$ 15,052	$ 23,306	$ 15,915	$ 22,338	$ 16,970	$ 12,656	$ 15,915
Brushless DC Evap. Fan Motor	33.24	$ 16,027	$ 23,413	$ 14,986	$ 23,139	$ 15,838	$ 22,182	$ 16,880	$ 12,618	$ 15,838
Enhanced-UA Evaporator Coil	31.40	$ 15,675	$ 22,652	$ 14,691	$ 22,393	$ 15,496	$ 21,489	$ 16,480	$ 12,454	$ 15,496
Permanent Split Cap. Cond. Fan Motor	31.32	$ 15,667	$ 22,626	$ 14,686	$ 22,368	$ 15,489	$ 21,467	$ 16,470	$ 12,455	$ 15,489
Enhanced-UA Condenser Coil	28.75	$ 15,514	$ 21,901	$ 14,613	$ 21,664	$ 15,350	$ 20,837	$ 16,251	$ 12,565	$ 15,350
Brushless DC Cond. Fan Motor	28.66	$ 15,528	$ 21,896	$ 14,630	$ 21,659	$ 15,364	$ 20,834	$ 16,262	$ 12,588	$ 15,364
Additional 1/2" Insulation	28.50	$ 15,637	$ 21,971	$ 14,744	$ 21,736	$ 15,475	$ 20,916	$ 16,368	$ 12,714	$ 15,475
Min LCC		$ 15,514	$ 21,896	$ 14,613	$ 21,659	$ 15,350	$ 20,834	$ 16,251	$ 12,454	$ 15,350
In situ (store) conditions										
Level	TEC/TDA	Australia	Brazil	China	EU	India	Japan	Mexico	RSA	USA
Baseline	31.48	$ 15,284	$ 22,278	$ 14,298	$ 22,018	$ 15,105	$ 21,113	$ 16,091	$ 12,056	$ 15,105
High-Eff. Reciprocating Compressor	29.62	$ 14,791	$ 21,372	$ 13,863	$ 21,127	$ 14,622	$ 20,275	$ 15,550	$ 11,753	$ 14,622
Permanent Split Cap. Evap. Fan Motor	29.28	$ 14,711	$ 21,218	$ 13,793	$ 20,976	$ 14,544	$ 20,134	$ 15,462	$ 11,708	$ 14,544
Brushless DC Evap. Fan Motor	28.87	$ 14,632	$ 21,047	$ 13,727	$ 20,808	$ 14,467	$ 19,978	$ 15,372	$ 11,671	$ 14,467
Enhanced-UA Evaporator Coil	27.33	$ 14,343	$ 20,416	$ 13,487	$ 20,190	$ 14,187	$ 19,404	$ 15,044	$ 11,540	$ 14,187
Permanent Split Cap. Cond. Fan Motor	27.23	$ 14,330	$ 20,381	$ 13,477	$ 20,156	$ 14,175	$ 19,372	$ 15,028	$ 11,538	$ 14,175
Enhanced-UA Condenser Coil	23.98	$ 13,905	$ 19,233	$ 13,154	$ 19,035	$ 13,769	$ 18,345	$ 14,520	$ 11,446	$ 13,769
Brushless DC Cond. Fan Motor	23.87	$ 13,916	$ 19,221	$ 13,168	$ 19,024	$ 13,780	$ 18,337	$ 14,528	$ 11,468	$ 13,780
Additional 1/2" Insulation	23.74	$ 14,036	$ 19,312	$ 13,292	$ 19,116	$ 13,900	$ 18,432	$ 14,644	$ 11,600	$ 13,900
Min LCC		$ 13,905	$ 19,221	$ 13,154	$ 19,024	$ 13,769	$ 18,337	$ 14,520	$ 11,446	$ 13,769

A.3 Glass lid ice cream chest freezer, integral (IHF6)

		Australia	Brazil	China	EU	India	Japan	Mexico	RSA	USA
Tariff (US$/kWh)		0.102	0.180	0.091	0.177	0.100	0.167	0.111	0.066	0.100
Life cycle costs per design option using the tariffs above										
ASHRAE test conditions										
Level	TEC/TDA	Australia	Brazil	China	EU	India	Japan	Mexico	RSA	USA
Baseline	15.23	$ 6,170	$ 7,615	$ 5,966	$ 7,561	$ 6,133	$ 7,374	$ 6,337	$ 5,503	$ 6,133
High-Eff. R	13.86	$ 6,029	$ 7,344	$ 5,843	$ 7,295	$ 5,995	$ 7,125	$ 6,181	$ 5,422	$ 5,995
Permanent	13.38	$ 5,988	$ 7,257	$ 5,809	$ 7,210	$ 5,955	$ 7,046	$ 6,134	$ 5,402	$ 5,955
High-Perfo	7.77	$ 5,657	$ 6,394	$ 5,553	$ 6,367	$ 5,638	$ 6,272	$ 5,742	$ 5,317	$ 5,638
Brushless	7.42	$ 5,660	$ 6,364	$ 5,561	$ 6,338	$ 5,642	$ 6,247	$ 5,742	$ 5,335	$ 5,642
Additional	6.98	$ 5,787	$ 6,449	$ 5,694	$ 6,424	$ 5,770	$ 6,339	$ 5,863	$ 5,481	$ 5,770
Min LCC		$ 5,657	$ 6,364	$ 5,553	$ 6,338	$ 5,638	$ 6,247	$ 5,742	$ 5,317	$ 5,638
EN-ISO test conditions										
Level	TEC/TDA	Australia	Brazil	China	EU	India	Japan	Mexico	RSA	USA
Baseline	15.65	$ 6,224	$ 7,709	$ 6,015	$ 7,654	$ 6,186	$ 7,462	$ 6,396	$ 5,539	$ 6,186
High-Eff. R	14.25	$ 6,079	$ 7,430	$ 5,888	$ 7,380	$ 6,044	$ 7,205	$ 6,234	$ 5,455	$ 6,044
Permanent	13.75	$ 6,036	$ 7,340	$ 5,852	$ 7,292	$ 6,002	$ 7,123	$ 6,186	$ 5,434	$ 6,002
High-Perfo	8.02	$ 5,690	$ 6,451	$ 5,583	$ 6,423	$ 5,670	$ 6,324	$ 5,778	$ 5,339	$ 5,670
Brushless	7.66	$ 5,692	$ 6,418	$ 5,589	$ 6,391	$ 5,673	$ 6,297	$ 5,775	$ 5,356	$ 5,673
Additional	7.21	$ 5,817	$ 6,501	$ 5,720	$ 6,476	$ 5,799	$ 6,387	$ 5,896	$ 5,501	$ 5,799
Min LCC		$ 5,690	$ 6,418	$ 5,583	$ 6,391	$ 5,670	$ 6,297	$ 5,775	$ 5,339	$ 5,670
In situ (store) conditions										
Level	TEC/TDA	Australia	Brazil	China	EU	India	Japan	Mexico	RSA	USA
Baseline	13.98889	$ 6,011	$ 7,338	$ 5,823	$ 7,288	$ 5,977	$ 7,116	$ 6,164	$ 5,398	$ 5,977
High-Eff. R	12.73	$ 5,883	$ 7,091	$ 5,713	$ 7,047	$ 5,853	$ 6,890	$ 6,023	$ 5,326	$ 5,853
Permanent	12.29	$ 5,848	$ 7,013	$ 5,683	$ 6,970	$ 5,818	$ 6,819	$ 5,982	$ 5,310	$ 5,818
High-Perfo	7.11	$ 5,570	$ 6,244	$ 5,475	$ 6,219	$ 5,553	$ 6,132	$ 5,648	$ 5,259	$ 5,553
Brushless	6.78	$ 5,577	$ 6,220	$ 5,486	$ 6,196	$ 5,560	$ 6,113	$ 5,651	$ 5,280	$ 5,560
Additional	6.38	$ 5,708	$ 6,313	$ 5,623	$ 6,290	$ 5,692	$ 6,212	$ 5,778	$ 5,429	$ 5,692
Min LCC		$ 5,570	$ 6,220	$ 5,475	$ 6,196	$ 5,553	$ 6,113	$ 5,648	$ 5,259	$ 5,553

A.4 Glass door (vertical) bottle cooler, integral (IVC4)

		Australia	Brazil	China	EU	India	Japan	Mexico	South Afric	USA
Tariff (US$/kWh)		0.102	0.180	0.091	0.177	0.100	0.167	0.111	0.066	0.100
Life cycle costs per design option using the tariffs above										
ASHRAE test conditions										
Level	TEC/TDA	Australia	Brazil	China	EU	India	Japan	Mexico	South Afric	USA
Baseline	15.79	$ 19,020	$ 26,618	$ 17,949	$ 26,335	$ 18,826	$ 25,352	$ 19,897	$ 15,514	$ 18,826
High-Eff. R	14.84	$ 18,473	$ 25,618	$ 17,466	$ 25,352	$ 18,290	$ 24,427	$ 19,298	$ 15,176	$ 18,290
Permanent	14.31	$ 18,163	$ 25,048	$ 17,192	$ 24,792	$ 17,986	$ 23,900	$ 18,957	$ 14,985	$ 17,986
Brushless	13.64	$ 17,813	$ 24,377	$ 16,888	$ 24,133	$ 17,645	$ 23,283	$ 18,571	$ 14,784	$ 17,645
Enhanced-	12.75	$ 17,376	$ 23,515	$ 16,511	$ 23,287	$ 17,219	$ 22,492	$ 18,085	$ 14,543	$ 17,219
LED Lighti	10.93	$ 16,755	$ 22,015	$ 16,014	$ 21,819	$ 16,620	$ 21,138	$ 17,362	$ 14,328	$ 16,620
High-Perfo	8.98	$ 16,558	$ 20,878	$ 15,948	$ 20,717	$ 16,447	$ 20,158	$ 17,056	$ 14,564	$ 16,447
Enhanced-	8.02	$ 16,344	$ 20,203	$ 15,800	$ 20,059	$ 16,246	$ 19,560	$ 16,790	$ 14,564	$ 16,246
Permanent	7.97	$ 16,341	$ 20,175	$ 15,801	$ 20,032	$ 16,243	$ 19,536	$ 16,784	$ 14,572	$ 16,243
Brushless	7.90	$ 16,371	$ 20,174	$ 15,835	$ 20,033	$ 16,273	$ 19,540	$ 16,810	$ 14,616	$ 16,273
Additional	7.81	$ 16,447	$ 20,204	$ 15,917	$ 20,065	$ 16,351	$ 19,578	$ 16,880	$ 14,713	$ 16,351
Min LCC		$ 16,341	$ 20,174	$ 15,800	$ 20,032	$ 16,243	$ 19,536	$ 16,784	$ 14,328	$ 16,243
EN-ISO test conditions										
Level	TEC/TDA	Australia	Brazil	China	EU	India	Japan	Mexico	South Afric	USA
Baseline	14.41	$ 18,136	$ 25,072	$ 17,158	$ 24,814	$ 17,958	$ 23,916	$ 18,936	$ 14,935	$ 17,958
High-Eff. R	13.53	$ 17,624	$ 24,133	$ 16,706	$ 23,891	$ 17,457	$ 23,048	$ 18,375	$ 14,619	$ 17,457
Permanent	12.99	$ 17,313	$ 23,563	$ 16,432	$ 23,331	$ 17,153	$ 22,521	$ 18,034	$ 14,429	$ 17,153
Brushless	12.32	$ 16,964	$ 22,894	$ 16,128	$ 22,673	$ 16,812	$ 21,905	$ 17,648	$ 14,227	$ 16,812
Enhanced-	11.50	$ 16,558	$ 22,090	$ 15,778	$ 21,885	$ 16,416	$ 21,168	$ 17,196	$ 14,004	$ 16,416
LED Lighti	10.58	$ 16,511	$ 21,603	$ 15,793	$ 21,414	$ 16,381	$ 20,755	$ 17,099	$ 14,161	$ 16,381
High-Perfo	8.61	$ 16,303	$ 20,447	$ 15,719	$ 20,293	$ 16,197	$ 19,756	$ 16,781	$ 14,391	$ 16,197
Enhanced-	7.76	$ 16,135	$ 19,869	$ 15,608	$ 19,730	$ 16,039	$ 19,247	$ 16,566	$ 14,412	$ 16,039
Permanent	7.71	$ 16,132	$ 19,841	$ 15,609	$ 19,703	$ 16,037	$ 19,223	$ 16,560	$ 14,420	$ 16,037
Brushless	7.64	$ 16,162	$ 19,841	$ 15,643	$ 19,704	$ 16,068	$ 19,228	$ 16,586	$ 14,464	$ 16,068
Additional	7.54	$ 16,235	$ 19,866	$ 15,723	$ 19,731	$ 16,142	$ 19,261	$ 16,654	$ 14,559	$ 16,142
Min LCC		$ 16,132	$ 19,841	$ 15,608	$ 19,703	$ 16,037	$ 19,223	$ 16,560	$ 14,004	$ 16,037
In situ (store) conditions										
Level	TEC/TDA	Australia	Brazil	China	EU	India	Japan	Mexico	South Afric	USA
Baseline	13.64	$ 17,626	$ 24,189	$ 16,701	$ 23,945	$ 17,458	$ 23,095	$ 18,383	$ 14,597	$ 17,458
High-Eff. R	12.81	$ 17,152	$ 23,318	$ 16,283	$ 23,088	$ 16,994	$ 22,290	$ 17,864	$ 14,307	$ 16,994
Permanent	12.27	$ 16,842	$ 22,748	$ 16,009	$ 22,528	$ 16,691	$ 21,763	$ 17,523	$ 14,116	$ 16,691
Brushless	11.61	$ 16,494	$ 22,079	$ 15,706	$ 21,871	$ 16,350	$ 21,148	$ 17,138	$ 13,916	$ 16,350
Enhanced-	10.85	$ 16,121	$ 21,341	$ 15,384	$ 21,146	$ 15,987	$ 20,471	$ 16,723	$ 13,711	$ 15,987
LED Lighti	9.93	$ 16,075	$ 20,855	$ 15,401	$ 20,677	$ 15,952	$ 20,058	$ 16,626	$ 13,869	$ 15,952
High-Perfo	8.01	$ 15,897	$ 19,750	$ 15,353	$ 19,607	$ 15,798	$ 19,108	$ 16,341	$ 14,118	$ 15,798
Enhanced-	6.89	$ 15,538	$ 18,854	$ 15,070	$ 18,731	$ 15,453	$ 18,301	$ 15,920	$ 14,007	$ 15,453
Permanent	6.85	$ 15,539	$ 18,835	$ 15,075	$ 18,712	$ 15,455	$ 18,286	$ 15,920	$ 14,018	$ 15,455
Brushless	6.79	$ 15,576	$ 18,845	$ 15,115	$ 18,724	$ 15,492	$ 18,300	$ 15,953	$ 14,067	$ 15,492
Additional	6.71	$ 15,660	$ 18,889	$ 15,204	$ 18,769	$ 15,577	$ 18,351	$ 16,032	$ 14,169	$ 15,577
Min LCC		$ 15,538	$ 18,835	$ 15,070	$ 18,712	$ 15,453	$ 18,286	$ 15,920	$ 13,711	$ 15,453

A.5 Vertical Open multi-deck, cooled, remote (RVC2)

		Australia	Brazil	China	EU	India	Japan	Mexico	RSA	USA
Tariff (US$/kWh)		0.102	0.180	0.091	0.177	0.056	0.167	0.111	0.066	0.100
Life cycle costs per design option using the tariffs above										
ASHRAE test conditions										
Level	TEC/TDA	Australia	Brazil	China	EU	India	Japan	Mexico	RSA	USA
Baseline	11.23	$ 26,593	$ 37,678	$ 25,030	$ 37,266	$ 20,056	$ 35,831	$ 27,872	$ 21,477	$ 26,309
Improved lighting	10.96	$ 26,445	$ 37,258	$ 24,920	$ 36,856	$ 20,068	$ 35,456	$ 27,693	$ 21,454	$ 26,168
LED lighting	10.16	$ 25,843	$ 35,870	$ 24,429	$ 35,498	$ 19,929	$ 34,199	$ 27,000	$ 21,215	$ 25,586
Nightcovers	8.52	$ 24,497	$ 32,903	$ 23,311	$ 32,590	$ 19,539	$ 31,502	$ 25,467	$ 20,617	$ 24,281
PSC evaporator fan motor	8.00	$ 23,913	$ 31,809	$ 22,799	$ 31,515	$ 19,256	$ 30,493	$ 24,824	$ 20,268	$ 23,710
ECM evaporator fan motor	7.35	$ 23,278	$ 30,536	$ 22,254	$ 30,266	$ 18,997	$ 29,326	$ 24,115	$ 19,928	$ 23,091
Larger evaporator coil	7.07	$ 23,481	$ 30,462	$ 22,496	$ 30,202	$ 19,363	$ 29,298	$ 24,286	$ 20,259	$ 23,302
Increased insulation	7.02	$ 23,543	$ 30,473	$ 22,565	$ 30,215	$ 19,456	$ 29,318	$ 24,342	$ 20,344	$ 23,365
Glass doors	5.73	$ 25,892	$ 31,551	$ 25,094	$ 31,341	$ 22,554	$ 30,608	$ 26,545	$ 23,280	$ 25,747
Min LCC		$ 23,278	$ 30,462	$ 22,254	$ 30,202	$ 18,997	$ 29,298	$ 24,115	$ 19,928	$ 23,091
EN-ISO test conditions										
Level	TEC/TDA	Australia	Brazil	China	EU	India	Japan	Mexico	RSA	USA
Baseline	10.08	$ 25,157	$ 35,104	$ 23,754	$ 34,734	$ 19,291	$ 33,446	$ 26,305	$ 20,566	$ 24,902
Improved lighting	9.95	$ 25,192	$ 35,009	$ 23,808	$ 34,644	$ 19,403	$ 33,373	$ 26,325	$ 20,661	$ 24,940
LED lighting	9.54	$ 25,091	$ 34,507	$ 23,764	$ 34,157	$ 19,539	$ 32,938	$ 26,178	$ 20,746	$ 24,850
Nightcovers	7.68	$ 23,467	$ 31,051	$ 22,398	$ 30,769	$ 18,995	$ 29,787	$ 24,342	$ 19,967	$ 23,273
PSC evaporator fan motor	7.17	$ 22,881	$ 29,954	$ 21,884	$ 29,691	$ 18,710	$ 28,775	$ 23,697	$ 19,617	$ 22,700
ECM evaporator fan motor	6.53	$ 22,253	$ 28,694	$ 21,345	$ 28,454	$ 18,455	$ 27,620	$ 22,996	$ 19,281	$ 22,088
Larger evaporator coil	6.22	$ 22,451	$ 28,586	$ 21,585	$ 28,358	$ 18,832	$ 27,563	$ 23,158	$ 19,619	$ 22,293
Increased insulation	6.16	$ 22,509	$ 28,590	$ 21,651	$ 28,364	$ 18,922	$ 27,576	$ 23,210	$ 19,702	$ 22,353
Glass doors	4.71	$ 24,634	$ 29,283	$ 23,978	$ 29,110	$ 21,892	$ 28,508	$ 25,170	$ 22,488	$ 24,515
Min LCC		$ 22,253	$ 28,586	$ 21,345	$ 28,358	$ 18,455	$ 27,563	$ 22,996	$ 19,281	$ 22,088
In situ (store) conditions										
Level	TEC/TDA	Australia	Brazil	China	EU	India	Japan	Mexico	RSA	USA
Baseline	8.14	$ 22,414	$ 30,451	$ 21,280	$ 30,152	$ 17,674	$ 29,111	$ 23,341	$ 18,704	$ 22,208
Improved lighting	8.00	$ 22,442	$ 30,340	$ 21,328	$ 30,046	$ 17,784	$ 29,023	$ 23,353	$ 18,796	$ 22,239
LED lighting	7.61	$ 19,157	$ 26,663	$ 18,098	$ 26,384	$ 14,730	$ 25,412	$ 20,023	$ 15,692	$ 18,964
Nightcovers	6.30	$ 18,162	$ 24,381	$ 17,285	$ 24,149	$ 14,494	$ 23,344	$ 18,879	$ 15,291	$ 18,002
PSC evaporator fan motor	5.79	$ 17,573	$ 23,285	$ 16,767	$ 23,073	$ 14,204	$ 22,333	$ 18,232	$ 14,936	$ 17,426
ECM evaporator fan motor	5.14	$ 16,914	$ 21,987	$ 16,199	$ 21,799	$ 13,922	$ 21,142	$ 17,499	$ 14,572	$ 16,784
Larger evaporator coil	4.92	$ 17,022	$ 21,880	$ 16,337	$ 21,700	$ 14,157	$ 21,070	$ 17,583	$ 14,780	$ 16,898
Increased insulation	4.88	$ 17,081	$ 21,897	$ 16,402	$ 21,718	$ 14,241	$ 21,095	$ 17,637	$ 14,859	$ 16,958
Glass doors	3.87	$ 19,340	$ 23,155	$ 18,802	$ 23,013	$ 17,090	$ 22,519	$ 19,780	$ 17,579	$ 19,242
Min LCC		$ 16,914	$ 21,880	$ 16,199	$ 21,700	$ 13,922	$ 21,070	$ 17,499	$ 14,572	$ 16,784

A.6 Vertical Open multi-deck, cooled, integral (IVC2)

		Australia	Brazil	China	EU	India	Japan	Mexico	RSA	USA
Tariff (US$/kWh)		0.102	0.180	0.091	0.177	0.056	0.167	0.111	0.066	0.100
Life cycle costs per design option using the tariffs above										
ASHRAE test conditions										
Level	TEC/TDA	Australia	Brazil	China	EU	India	Japan	Mexico	RSA	USA
Baseline	27.84	$ 17,220	$ 24,915	$ 16,135	$ 24,629	$ 12,682	$ 23,632	$ 18,108	$ 13,669	$ 17,023
Super T8 Lighting*	27.48	$ 17,182	$ 24,776	$ 16,111	$ 24,494	$ 12,703	$ 23,511	$ 18,058	$ 13,677	$ 16,987
LED Lighting	25.81	$ 16,739	$ 23,874	$ 15,733	$ 23,609	$ 12,531	$ 22,685	$ 17,562	$ 13,446	$ 16,556
Night covers	20.52	$ 15,108	$ 20,779	$ 14,308	$ 20,568	$ 11,763	$ 19,833	$ 15,762	$ 12,490	$ 14,962
Permanent Split Cap. Evap. Fan Motor	20.06	$ 14,976	$ 20,520	$ 14,194	$ 20,314	$ 11,706	$ 19,596	$ 15,616	$ 12,417	$ 14,834
Permanent Split Cap. Cond. Fan Motor	19.82	$ 14,939	$ 20,417	$ 14,167	$ 20,213	$ 11,709	$ 19,504	$ 15,571	$ 12,411	$ 14,799
Brushless DC Evap. Fan Motor	19.25	$ 14,817	$ 20,138	$ 14,066	$ 19,940	$ 11,678	$ 19,251	$ 15,431	$ 12,361	$ 14,680
Enhanced-UA Evaporator Coil	18.69	$ 14,852	$ 20,019	$ 14,123	$ 19,827	$ 11,805	$ 19,158	$ 15,448	$ 12,467	$ 14,719
High-Eff. Reciprocating Compressor	17.97	$ 14,626	$ 19,593	$ 13,926	$ 19,408	$ 11,697	$ 18,765	$ 15,199	$ 12,334	$ 14,499
Brushless DC Cond. Fan Motor	17.70	$ 14,651	$ 19,544	$ 13,961	$ 19,362	$ 11,766	$ 18,728	$ 15,216	$ 12,393	$ 14,526
Enhanced-UA Condenser Coil	16.37	$ 14,945	$ 19,471	$ 14,307	$ 19,303	$ 12,276	$ 18,717	$ 15,467	$ 12,856	$ 14,829
Additional 1/2" Insulation	16.31	$ 15,082	$ 19,591	$ 14,446	$ 19,423	$ 12,422	$ 18,839	$ 15,602	$ 13,000	$ 14,966
Glass doors	12.53	$ 15,277	$ 18,742	$ 14,789	$ 18,613	$ 13,234	$ 18,164	$ 15,677	$ 13,678	$ 15,189
Min LCC		$ 14,626	$ 18,742	$ 13,926	$ 18,613	$ 11,678	$ 18,164	$ 15,199	$ 12,334	$ 14,499
EN-ISO test conditions										
Level	TEC/TDA	Australia	Brazil	China	EU	India	Japan	Mexico	RSA	USA
Baseline	29.04	$ 17,688	$ 25,715	$ 16,557	$ 25,416	$ 12,955	$ 24,377	$ 18,615	$ 13,984	$ 17,483
Super T8 Lighting*	28.86	$ 17,715	$ 25,691	$ 16,590	$ 25,395	$ 13,011	$ 24,362	$ 18,636	$ 14,034	$ 17,511
LED Lighting	27.78	$ 17,485	$ 25,165	$ 16,402	$ 24,879	$ 12,956	$ 23,885	$ 18,371	$ 13,940	$ 17,288
Night covers	21.50	$ 15,497	$ 21,440	$ 14,658	$ 21,219	$ 11,991	$ 20,449	$ 16,182	$ 12,753	$ 15,344
Permanent Split Cap. Evap. Fan Motor	21.04	$ 15,364	$ 21,181	$ 14,544	$ 20,965	$ 11,934	$ 20,211	$ 16,035	$ 12,680	$ 15,215
Permanent Split Cap. Cond. Fan Motor	20.78	$ 15,320	$ 21,064	$ 14,510	$ 20,851	$ 11,933	$ 20,107	$ 15,983	$ 12,669	$ 15,173
Brushless DC Evap. Fan Motor	20.22	$ 15,197	$ 20,785	$ 14,409	$ 20,577	$ 11,901	$ 19,853	$ 15,842	$ 12,618	$ 15,054
Enhanced-UA Evaporator Coil	19.60	$ 15,224	$ 20,641	$ 14,460	$ 20,440	$ 12,030	$ 19,738	$ 15,849	$ 12,724	$ 15,085
High-Eff. Reciprocating Compressor	18.81	$ 14,977	$ 20,177	$ 14,244	$ 19,984	$ 11,910	$ 19,310	$ 15,577	$ 12,577	$ 14,844
Brushless DC Cond. Fan Motor	18.52	$ 14,994	$ 20,114	$ 14,272	$ 19,923	$ 11,974	$ 19,260	$ 15,584	$ 12,631	$ 14,862
Enhanced-UA Condenser Coil	17.22	$ 15,341	$ 20,101	$ 14,670	$ 19,924	$ 12,534	$ 19,307	$ 15,890	$ 13,144	$ 15,219
Additional 1/2" Insulation	17.16	$ 15,475	$ 20,217	$ 14,806	$ 20,041	$ 12,678	$ 19,427	$ 16,022	$ 13,286	$ 15,353
Glass doors	12.56	$ 15,370	$ 18,842	$ 14,880	$ 18,713	$ 13,322	$ 18,263	$ 15,770	$ 13,767	$ 15,281
Min LCC		$ 14,977	$ 18,842	$ 14,244	$ 18,713	$ 11,901	$ 18,263	$ 15,577	$ 12,577	$ 14,844
In situ (store) conditions										
Level	TEC/TDA	Australia	Brazil	China	EU	India	Japan	Mexico	RSA	USA
Baseline	22.19	$ 15,026	$ 21,159	$ 14,161	$ 20,931	$ 11,409	$ 20,137	$ 15,734	$ 12,196	$ 14,869
Super T8 Lighting*	22.00	$ 15,052	$ 21,132	$ 14,194	$ 20,906	$ 11,466	$ 20,118	$ 15,753	$ 12,245	$ 14,896
LED Lighting	20.85	$ 14,796	$ 20,558	$ 13,984	$ 20,344	$ 11,398	$ 19,598	$ 15,461	$ 12,137	$ 14,649
Night covers	16.47	$ 13,505	$ 18,059	$ 12,863	$ 17,890	$ 10,820	$ 17,300	$ 14,031	$ 11,404	$ 13,389
Permanent Split Cap. Evap. Fan Motor	15.99	$ 13,364	$ 17,784	$ 12,741	$ 17,619	$ 10,758	$ 17,047	$ 13,874	$ 11,325	$ 13,251
Permanent Split Cap. Cond. Fan Motor	15.70	$ 13,312	$ 17,651	$ 12,700	$ 17,490	$ 10,752	$ 16,928	$ 13,812	$ 11,309	$ 13,200
Brushless DC Evap. Fan Motor	15.10	$ 13,179	$ 17,355	$ 12,591	$ 17,199	$ 10,717	$ 16,659	$ 13,661	$ 11,253	$ 13,072
Enhanced-UA Evaporator Coil	14.61	$ 13,187	$ 17,226	$ 12,618	$ 17,075	$ 10,806	$ 16,553	$ 13,653	$ 11,323	$ 13,084
High-Eff. Reciprocating Compressor	13.94	$ 12,981	$ 16,836	$ 12,438	$ 16,692	$ 10,709	$ 16,193	$ 13,426	$ 11,203	$ 12,883
Brushless DC Cond. Fan Motor	13.63	$ 12,991	$ 16,758	$ 12,460	$ 16,618	$ 10,770	$ 16,130	$ 13,426	$ 11,253	$ 12,895
Enhanced-UA Condenser Coil	12.21	$ 13,086	$ 16,460	$ 12,611	$ 16,335	$ 11,097	$ 15,898	$ 13,476	$ 11,529	$ 13,000
Additional 1/2" Insulation	12.15	$ 13,227	$ 16,585	$ 12,753	$ 16,460	$ 11,246	$ 16,025	$ 13,614	$ 11,677	$ 13,141
Glass doors	9.27	$ 13,777	$ 16,338	$ 13,416	$ 16,243	$ 12,266	$ 15,911	$ 14,073	$ 12,595	$ 13,711
Min LCC		$ 12,981	$ 16,338	$ 12,438	$ 16,243	$ 10,709	$ 15,898	$ 13,426	$ 11,203	$ 12,883

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