ALTERNATIVE COMMERCIAL REFRIGERATION SYSTEMS IN WARM CLIMATES

SPECIFIC CASE STUDY
SPAIN & PORTUGAL

G.I.T.

December 2016

Scientific research study promoted by Tewis

Thermal Engineering Research Group (GIT) "*Alternative refrigeration systems in warm climates. Specific case study: Spain and Portugal*" (2016).
Available in http://www.git.uji.es/inicio/docs/Inf_Sist_Ref_Comercial.pdf

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* **G.I.T. Research Group Introduction**
* Background
* Cascade System & Basic CO_2 *booster* cycle
* Analysis of alternative commercial refrigeration systems
* Acknowledgements

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G.I.T. Research Group Introduction

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G.I.T.
Thermal Installations Research Group
www.git.uji.es

Thermal Engineering Research Group

www.git.uji.es

Founded in 1998 placed in Jaume I University of Castellón

Team integrated by teachers and reserchers from Jaume I University

Refrigeration & Heat Transfer

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G.I.T. Research Group Introduction

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Thermal Installations Research Group
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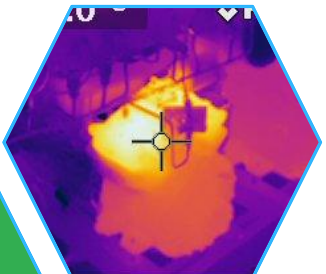
Over 50 International scientific articles

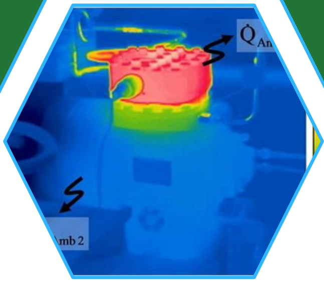
Over 45 International congress contributions



10 Scientific Books

28 National congress contributions

3 Research awards



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Background

* The main objective of this scientific research study was to compare different CO_2 refrigeration technologies that are in accordance with the F-GAS regulation.

* This study is mainly focused in warm climates such as Spain or Portugal.

* According to the study, different alternatives are available depending on the location or the environmental temperature profile along a year.

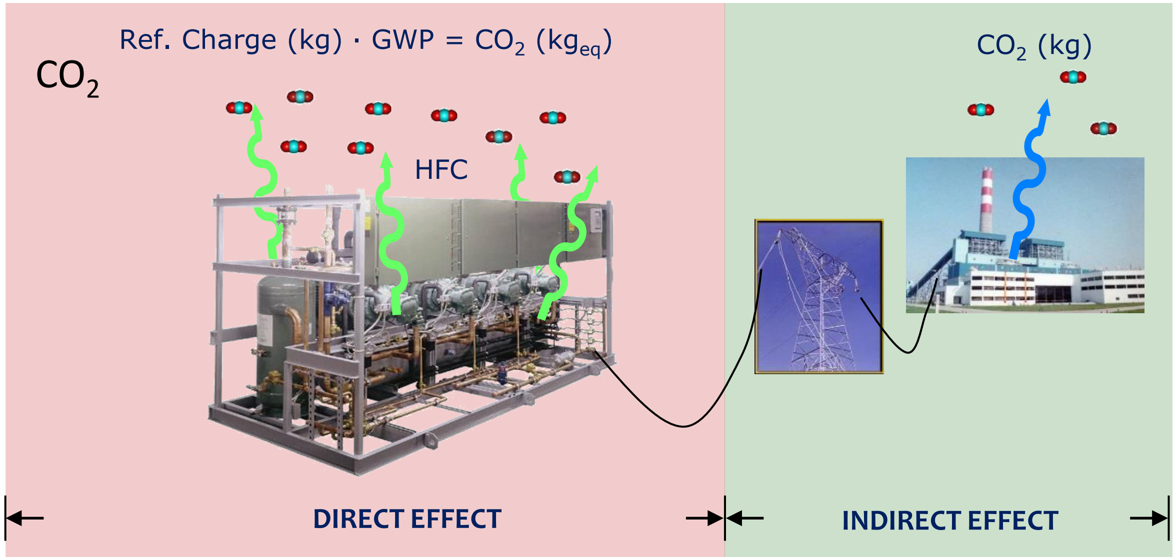
* For warm environment temperatures, the use of the basic CO_2 *booster configuration* entails a rise in the energy consumption regarding to the cascade system.

Background

Environmental Issues

The main environmental concern at this moment is focused on decreasing the Greenhouse Gas Emissions in order to diminish the Global Warming Impact.

In Commercial Refrigeration there are two ways to contribute with the Greenhouse Gas Emissions: Direct and Indirect emissions.

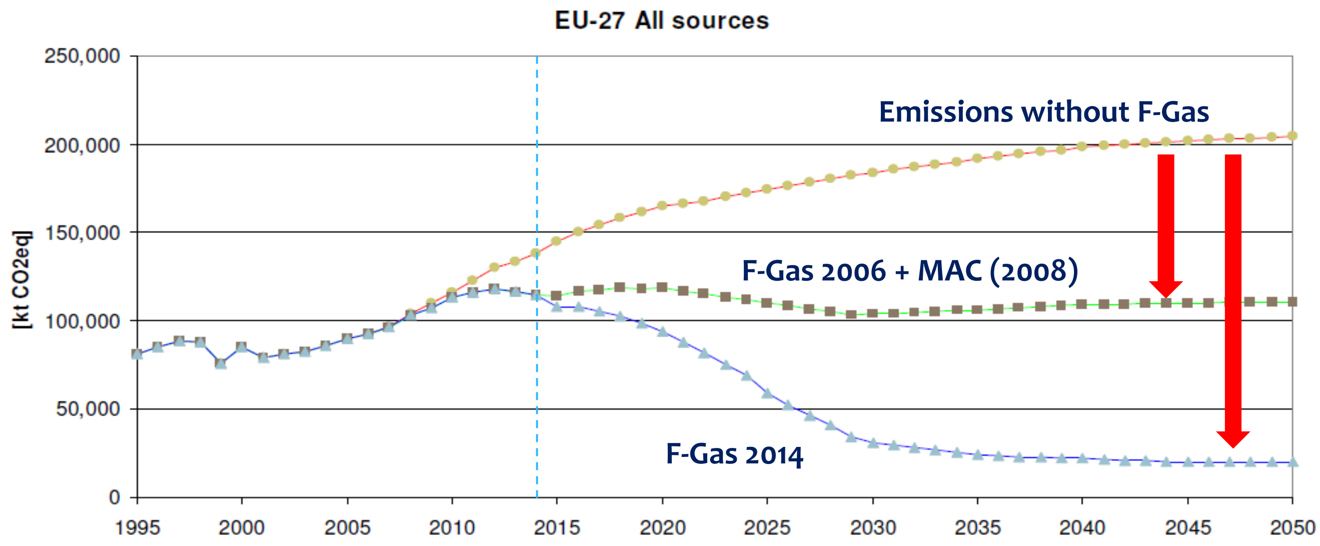


Background

European Regulation

The European Union aims to reduce the environmental impact of fluorinated gases through the F-Gas regulation (EU 517/2014), which came into force on the 1st January 2015

According to the F-Gas, non-CO_2 emissions including **fluorinated greenhouse gases**, should be reduced by 72 % to 73 % by 2030 and by 70 % to 78 % by 2050, compared to 1990 levels.



Preparatory study for a review of Regulation (EC) No 842/2006 on certain fluorinated greenhouse gases. W Schwarz *et al.* (2011)

Background

European Regulation

To achieve this objective, the F-Gas regulation establishes rules on containment, use, recovery and destruction of fluorinated greenhouse gases; imposes conditions on the placing on the market of specific products and equipment that contain, or whose functioning relies upon, fluorinated greenhouse gases; imposes conditions on specific uses of fluorinated greenhouse gases; and, finally, establishes quantitative limits for the placing on the market of hydrofluorocarbons

Article 11 (Annex III) – PLACING ON THE MARKET PROHIBITIONS

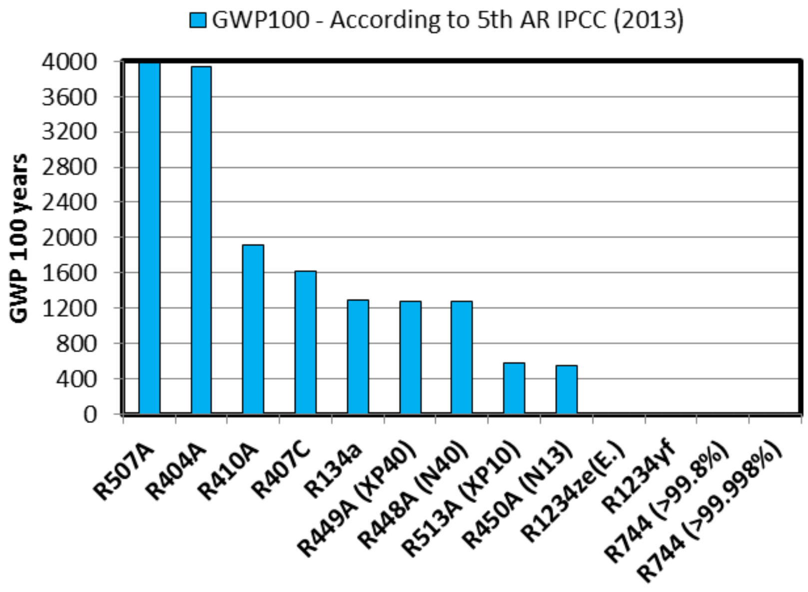
13. Multipack centralized refrigeration systems for commercial use with a rated capacity of 40 kW or more that contain, or whose functioning relies upon, fluorinated greenhouse gases with GWP of 150 or more, except in the primary refrigerant circuit of cascade systems where fluorinated greenhouse gases with a GWP of less than 1 500 may be used

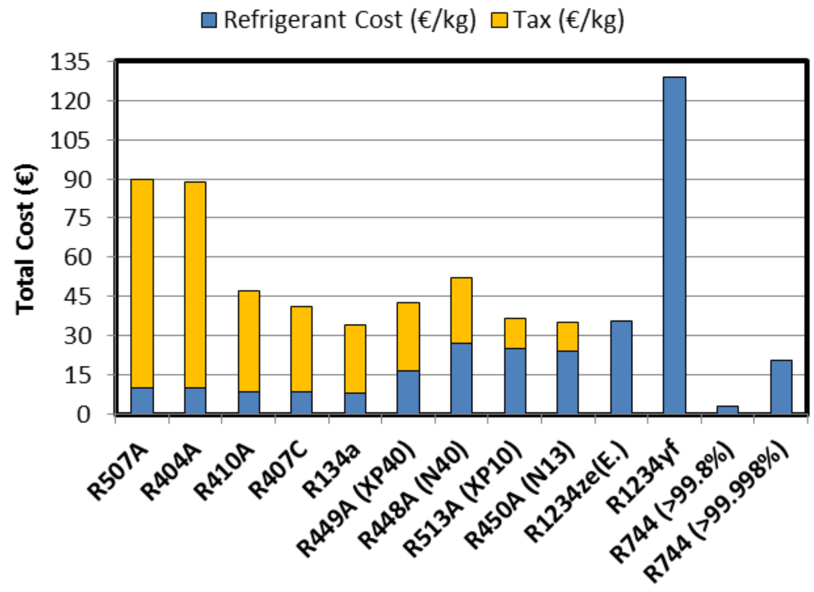
Date of prohibition: 1/01/2022

Background

Spanish Regulation

The Law 16/2013 aims to reduce the use of fluorinated greenhouse gases with GWP_{100} > 150 establishing an economic tax of **0.02 €/$kg_{CO2\ eq.}$** with a maximum value of 100 €.





Refrigerant cost is obtained from diferent suppliers (2016)

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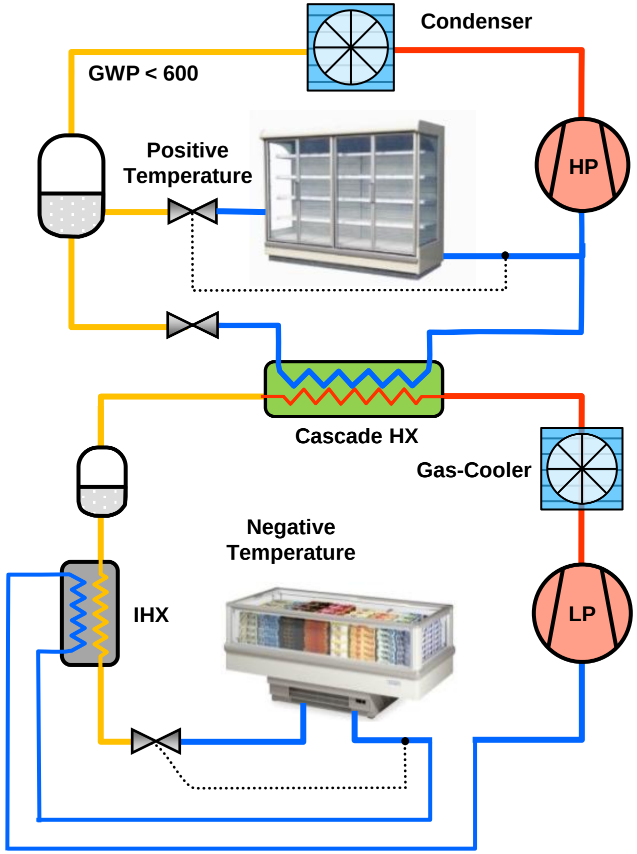
Cascade system
& Basic CO_2 *booster* cycle

Cascade system

A cascade system works with two refrigerants. The first one is used for positive temperature services in the primary circuit with low GWP (lower than 600 - AR5). The second one is located in the low temperature circuit for negative services. CO_2 is commonly used as a solution in this case.

This kind of systems will not be included in the F-GAS standard from 2022, in spite of its high efficiency values (COP) working in warm climates as can be checked later.



Sanz-Kock C., Llopis R., Sánchez D., Cabello R., Torrella E., *Experimental evaluation of a R134a/CO2 cascade refrigeration plant*, Applied Thermal Engineering, vol. 73, 1, pp 41-50 (2014).

Cabello R., Sánchez D., Llopis R., Catalán-Gil J., Nebot-Andrés L., Torrella E., *Energy evaluation of R152a as drop in replacement for R134a in cascade refrigeration plants*, Applied Thermal Engineering, vol. 110, 5, pp 972-984 (2017).

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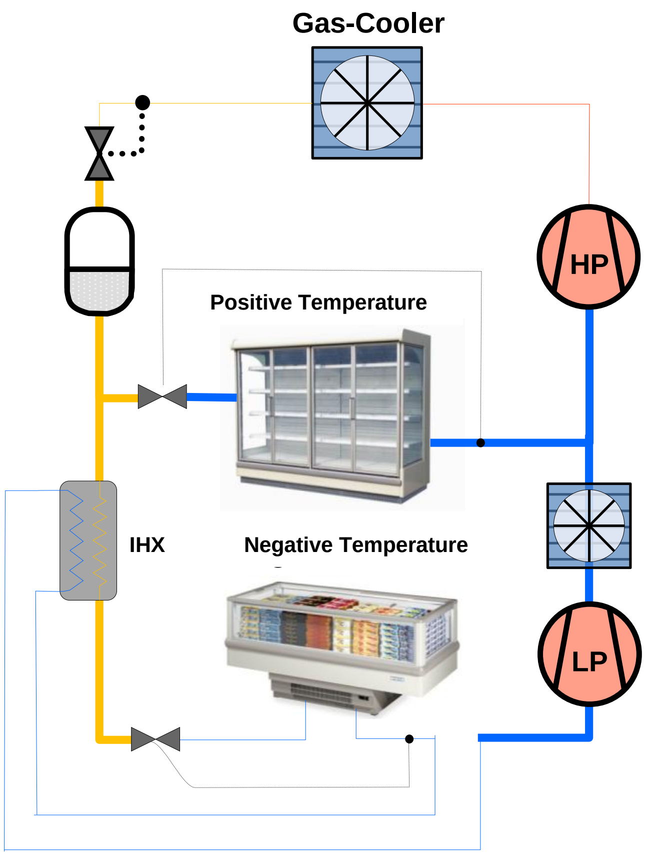
Cascade system
& Basic CO_2 *booster* cycle

Basic CO_2 *booster* system

Basic CO_2 *booster* system only uses CO_2 as a refrigerant so it is completely compatible with the F-Gas Regulation.

Due to its low critical temperature (~31°C) the cycle can work either transcritical or subcritical depending on the environment temperature. Accordingly, this kind of cycle needs a specific control system in order to operate in optimal conditions (optimal pressure that maximizes the global COP).



Cabello R., Sánchez D., Lopis R., Torrella E., *Experimental evaluation of the energy efficiency of a CO2 refrigerating plant working in transcritical conditions*, Applied Thermal Engineering, vol. 28, 13, pp 1596-1604 (2008).

Sánchez D., Patiño J., Sanz-Kock C., Lopis R., Cabello R., Torrella E., *Energetic evaluation of a CO2 refrigeration plant wrking in supercritical and subcritical conditions*, Applied Thermal Engineering, vol. 66, 1-2, pp 227-238 (2014).

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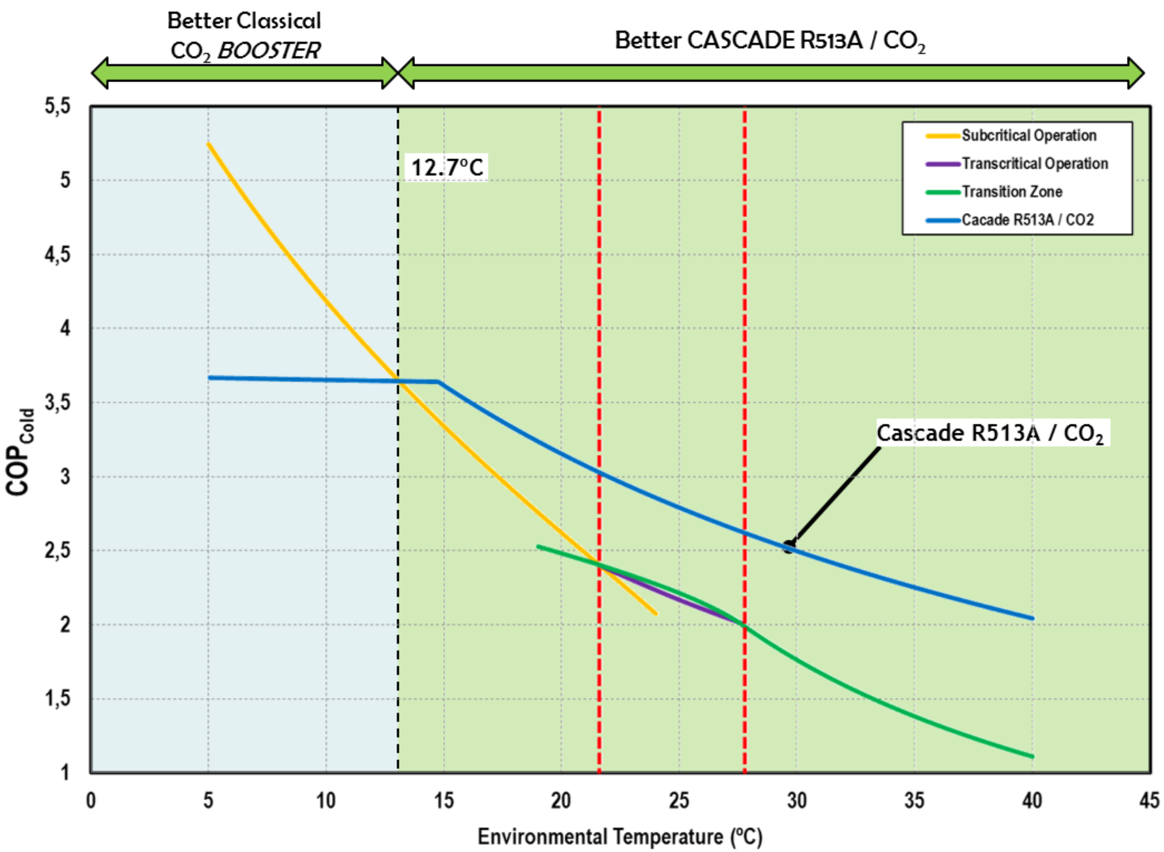
Cascade system
& Basic CO_2 *booster* cycle

Cascade system vs Basic CO_2 *booster* system



Positive Temperature

140 kW

-8 ºC in cascade system

-6ºC in CO_2 *booster* system

Negative Temperature

41 kW

-32 ºC in both cycles

The LMTD depends on the operating conditions. For subcritical conditions a ΔT=5 K is assumed in both systems. In transcritical conditions ΔT=2 K.

Useful superheating of 5 K is considered in both systems as well as a thermal effectiveness of 35% in the IHX.

Only optimal operating conditions are used in CO_2 *booster* system.

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Cascade system
& Basic CO_2 *booster* cycle

Cascade system vs Basic CO_2 *booster* system

* Depending on the location or the environment temperature, cascade or basic CO_2 *booster* systems can be adopted.

* Cascade system is suitable with environment temperature > 12.7°C .

* Basic *booster* CO_2 system is more appropriate for environment temperatures lower than 12.7 °C

* For warm environment temperatures, the use of the basic CO_2 *booster* configuration entails an important reduction in terms of COP, that is, more energy consumption. Accordingly, basic CO_2 *booster* configuration must be upgraded to increase its performance.

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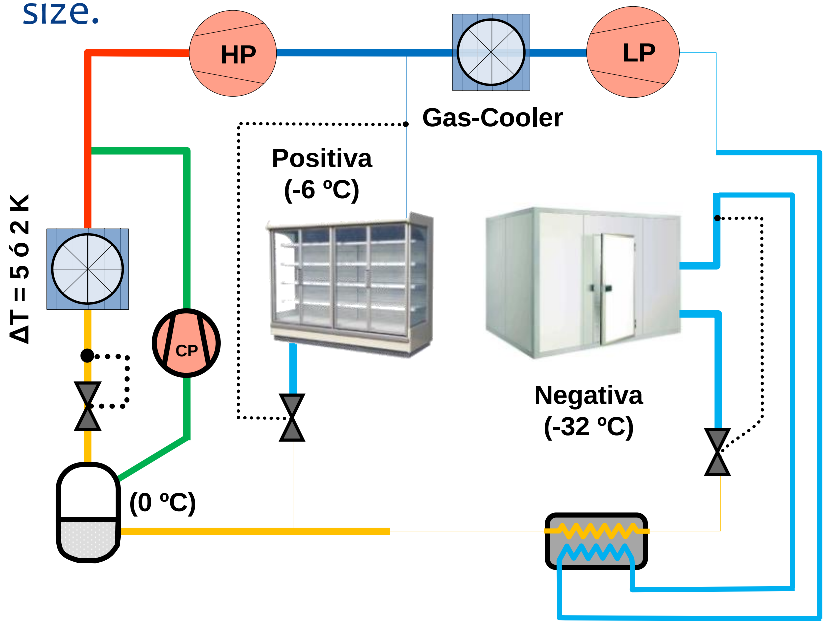
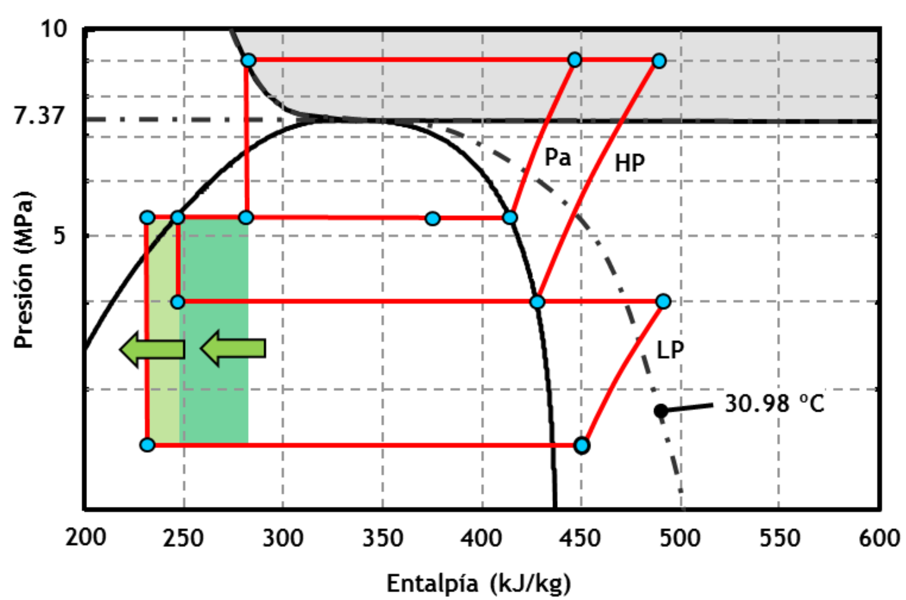
Alternative commercial refrigeration systems

Parallel compressor

The inclusion of a third compressor, commonly called parallel compressor (CP), allows extracting vapor from the receiver, thus increasing the enthalpy difference in the medium and low temperature evaporators. Furthermore, this compressor reduces the mass flow compressed by the high pressure compressor (HP) and reduces its power consumption and its size.

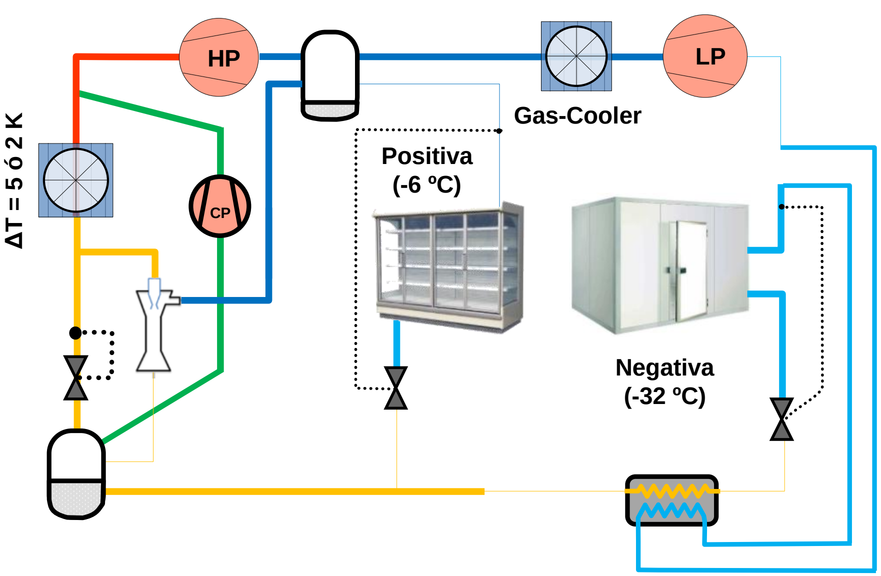


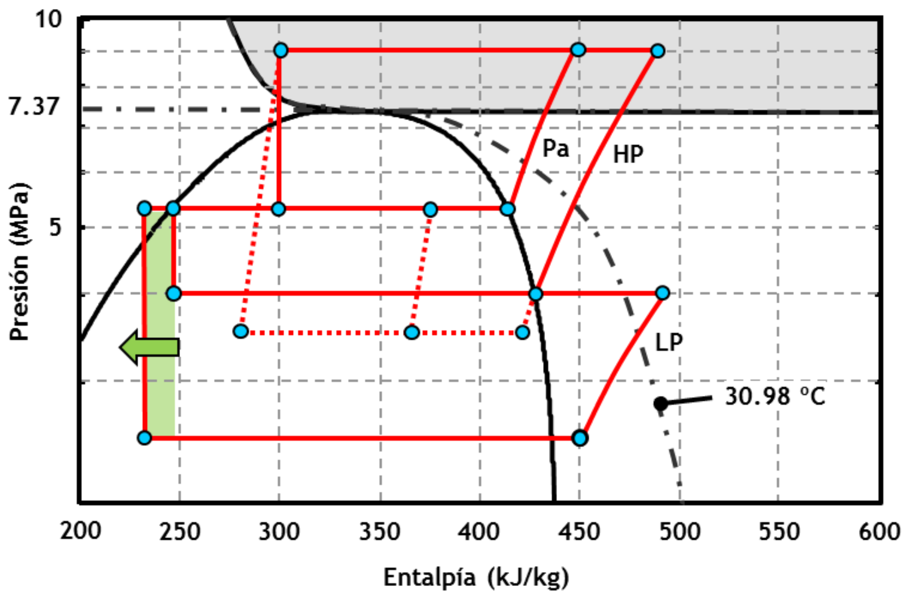


Alternative commercial refrigeration systems

Ejector + Parallel compressor

The ejector is a device that can increase pressure of a low pressure gas flow taking advantage of the depression generated when a high pressure flow passes through a nozzle. To use the ejector technology in a *booster* CO_2 cycle parallel compressor is recommended.

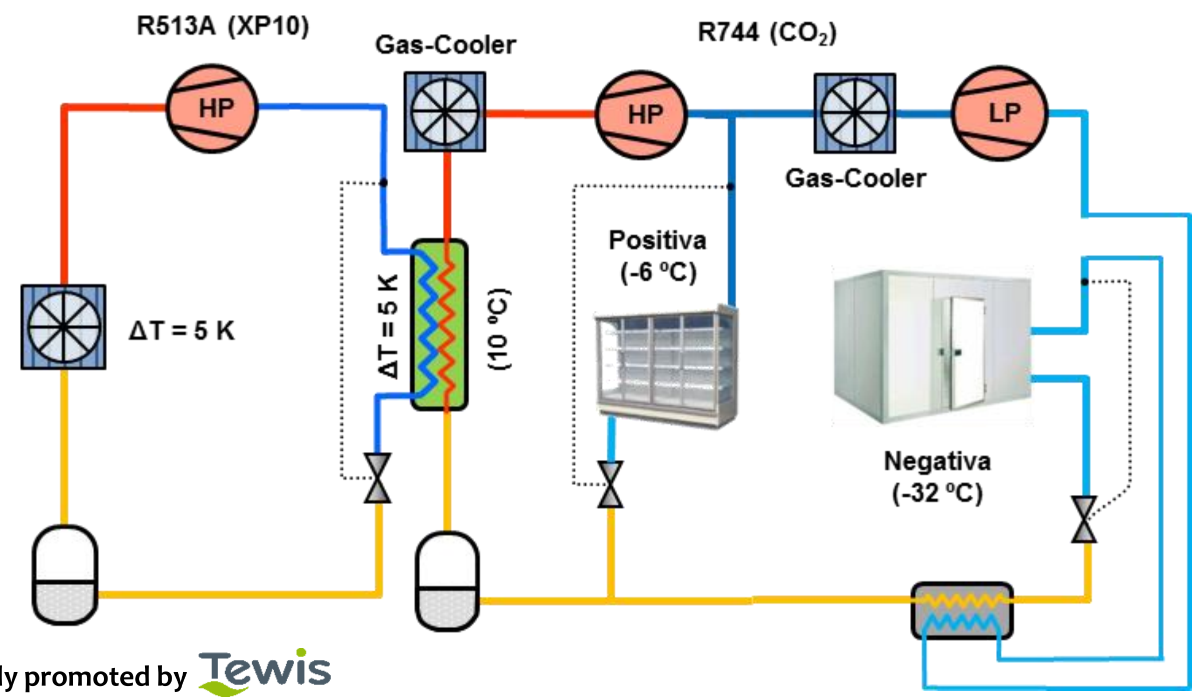




Alternative commercial refrigeration systems

Cascade system + basic CO_2 *booster* (Subcritical)

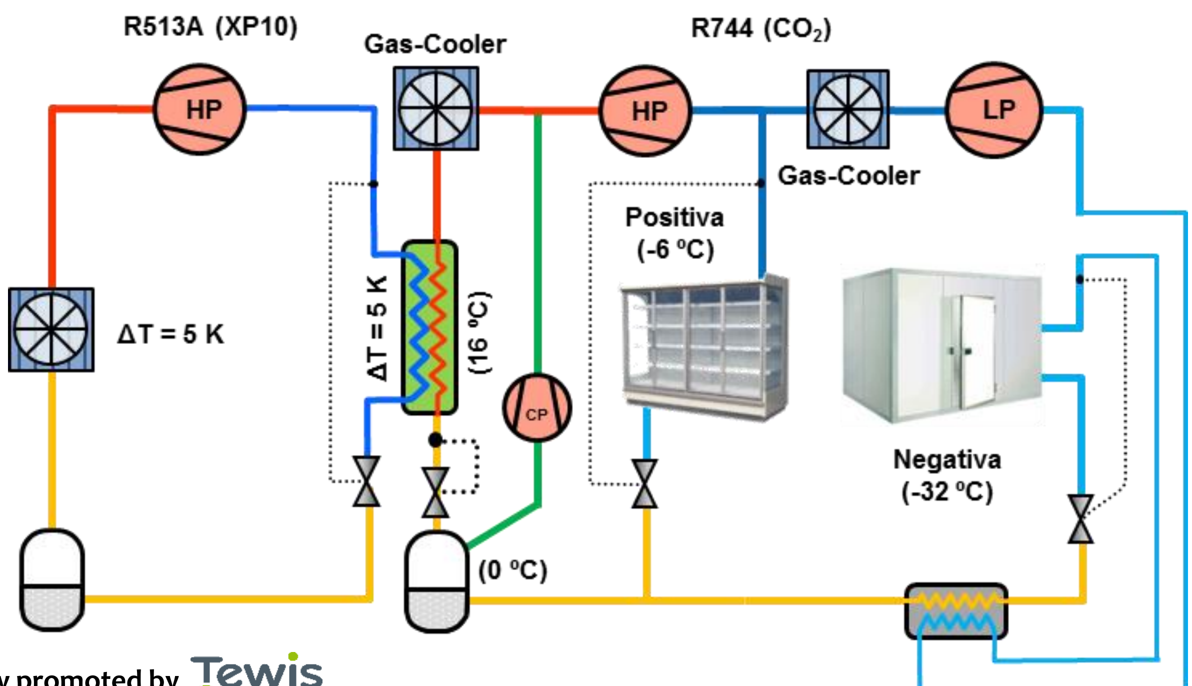
The high COP reduction due to the high external temperatures can be diminished forcing the *booster* cycle to work in subcritical conditions. In order to achieve this operation mode, a second vapour compression cycle with a different refrigerant (HFC, HFO or HC) could be used.



Alternative commercial refrigeration systems

Cascade system + basic CO_2 *booster* + Parallel compressor (Subcritical)

This configuration is quite similar to the previous one but it includes a parallel compressor in the CO_2 *booster* cycle. This configuration improves the performance and the COP of the previous one working at high environmental temperatures.



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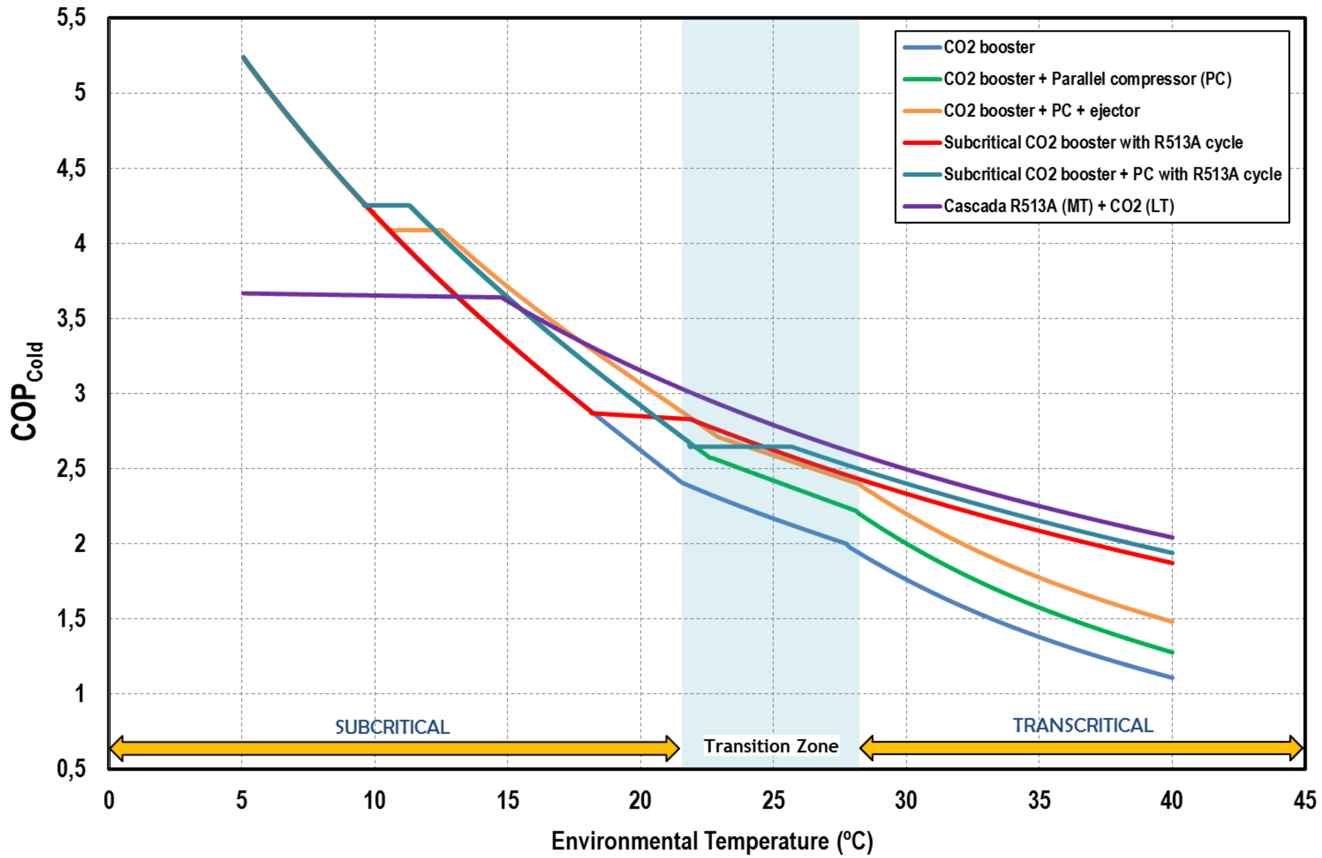
Alternative commercial refrigeration systems

COP

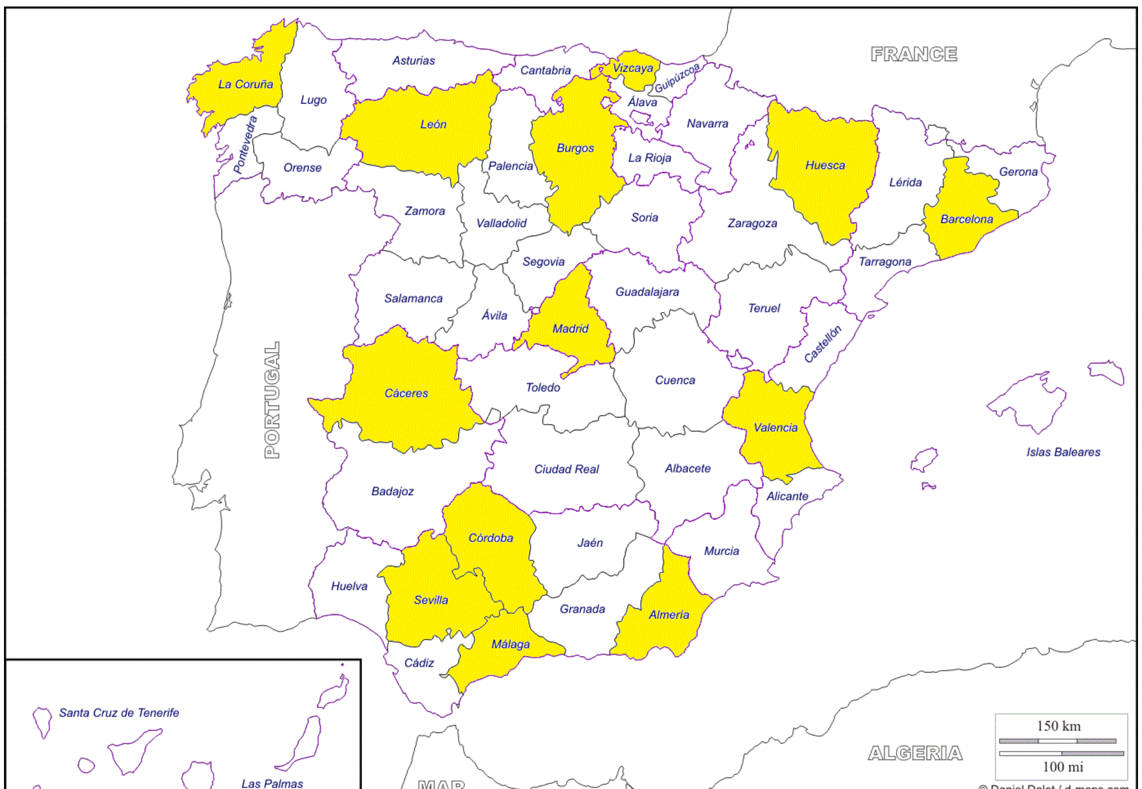


Classical CO_2 *booster* system has a reduced COP value regarding a cascade system.

Improvements on the classical CO_2 booster cycle allow increasing its COP, reaching values close to the cascade system ones, as can be show in the Figure.

Alternative commercial refrigeration systems

Energy Consumption



Country: **Spain**

<u>Cooling Load Demand Profile</u>

100% → 7 am – 22 pm

50% → rest of the day

<u>Temperature Profile</u>

Software *EnergyPlus* (2016)

<u>Positive Temperature</u>

140 kW

-8 ºC in cascade system

-6ºC in *booster* CO_2 systems

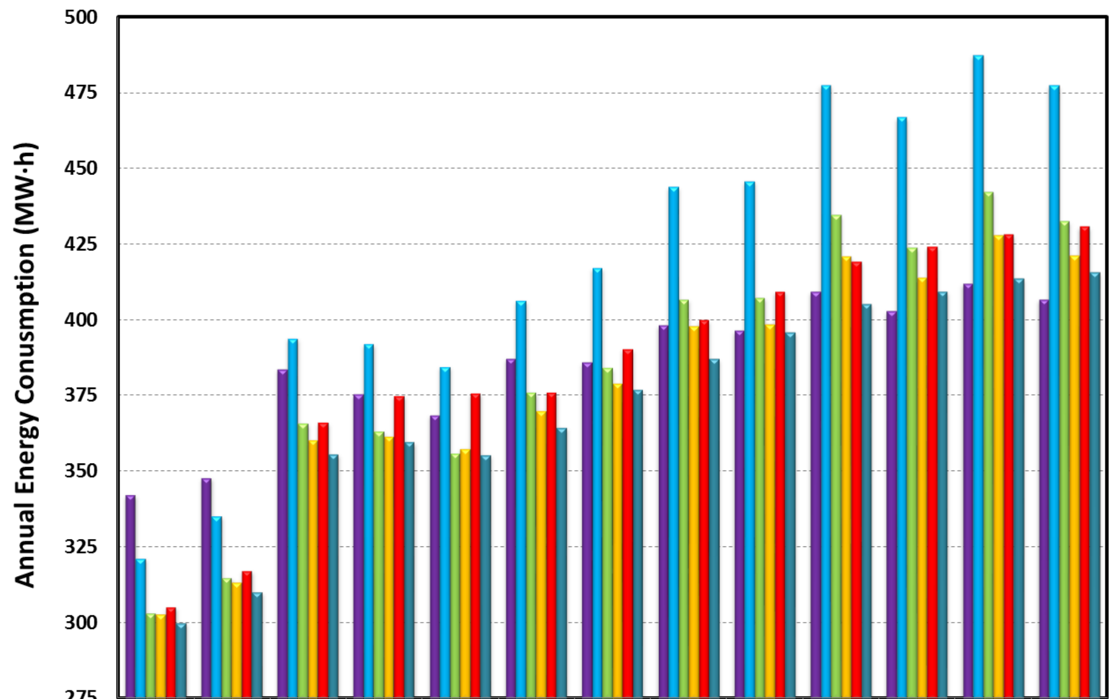
<u>Negative Temperature</u>

41 kW

-32 ºC in both cycles

Alternative commercial refrigeration systems

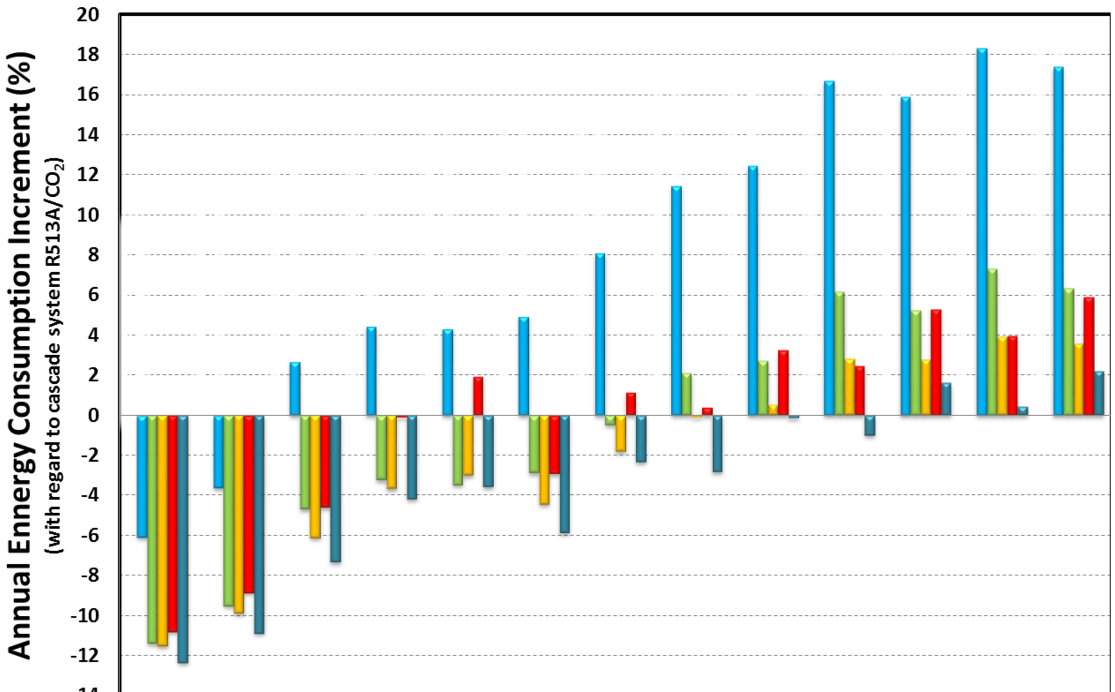
Energy Consumption



	Burgos	León	Huesca	Bilbao	La Coruña	Madrid	Barcelona	Cáceres	Valencia	Córdoba	Málaga	Sevilla	Almería
Cascade R513A / R744	342,17	347,90	383,75	375,36	368,60	387,24	385,94	398,34	396,52	409,35	402,87	411,98	406,83
CO2 booster	321,32	335,25	393,98	391,99	384,58	406,36	417,16	443,99	445,89	477,67	466,91	487,56	477,53
CO2 booster + Parallel compressor (PC)	303,22	314,85	365,77	363,23	355,83	376,06	384,10	406,78	407,39	434,64	423,94	442,14	432,57
CO2 booster + PC + ejector	302,76	313,48	360,32	361,56	357,51	370,04	378,95	397,91	398,62	420,85	413,96	428,08	421,40
Subcritical CO2 booster with R513A cycle	305,23	317,14	366,07	374,94	375,74	375,95	390,38	399,86	409,42	419,37	424,17	428,24	430,80
Subcritical CO2 booster + PC with R513A cycle	299,92	310,10	355,61	359,65	355,43	364,51	376,92	387,09	395,92	405,25	409,37	413,76	415,80

Alternative commercial refrigeration systems

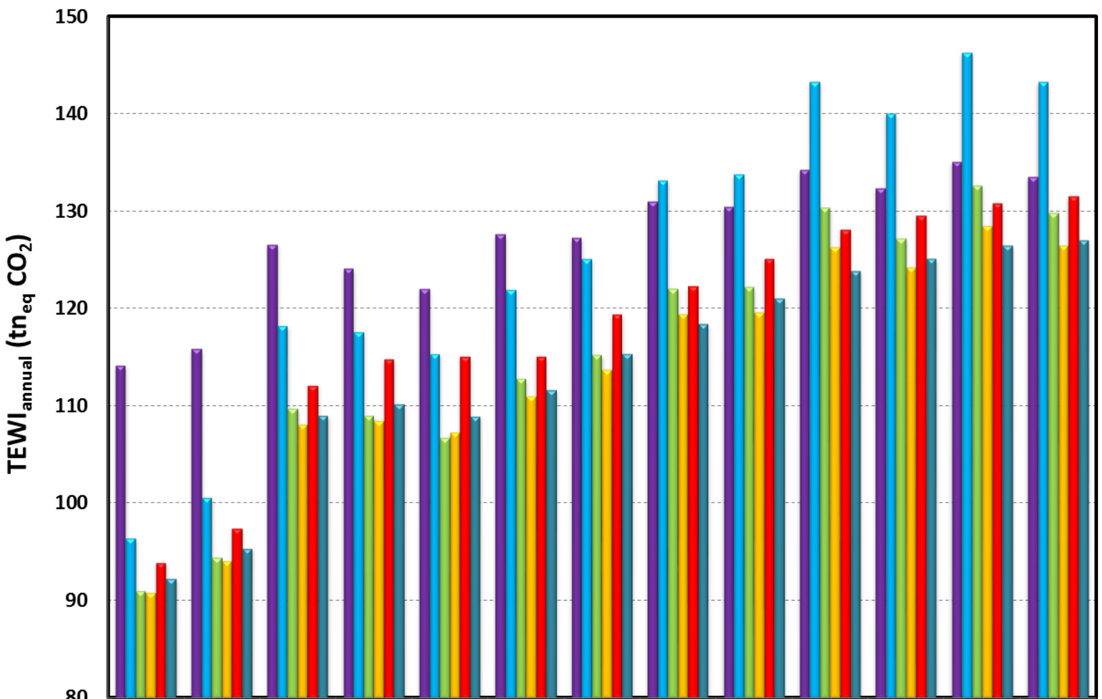
Energy Consumption



	Burgos	León	Huesca	Bilbao	La Coruña	Madrid	Barcelona	Cáceres	Valencia	Córdoba	Málaga	Sevilla	Almería
Annual Average Temperature (ºC)	9,89	10,75	13,40	14,03	14,12	14,31	15,34	16,17	16,74	17,45	17,96	18,21	18,51
CO2 booster	-6,09	-3,64	2,67	4,43	4,34	4,94	8,09	11,46	12,45	16,69	15,90	18,34	17,38
CO2 booster + Parallel compressor (PC)	-11,38	-9,50	-4,68	-3,23	-3,46	-2,89	-0,48	2,12	2,74	6,18	5,23	7,32	6,33
CO2 booster + PC + ejector	-11,52	-9,89	-6,11	-3,68	-3,01	-4,44	-1,81	-0,11	0,53	2,81	2,75	3,91	3,58
Subcritical CO2 booster with R513A cycle	-10,80	-8,84	-4,61	-0,11	1,94	-2,92	1,15	0,38	3,25	2,45	5,29	3,94	5,89
Subcritical CO2 booster + PC with R513A cycle	-12,35	-10,87	-7,33	-4,19	-3,57	-5,87	-2,34	-2,82	-0,15	-1,00	1,62	0,43	2,21

Alternative commercial refrigeration systems

Annual TEWI



	Burgos	León	Huesca	Bilbao	La Coruña	Madrid	Barcelona	Cáceres	Valencia	Córdoba	Málaga	Sevilla	Almería
Cascade R513A / R744	114,14	115,86	126,61	124,10	122,07	127,66	127,27	130,99	130,45	134,29	132,35	135,08	133,54
CO2 booster	96,42	100,60	118,21	117,62	115,40	121,93	125,17	133,22	133,79	143,32	140,09	146,29	143,28
CO2 booster + Parallel compressor (PC)	90,99	94,48	109,75	108,99	106,77	112,84	115,25	122,05	122,24	130,41	127,20	132,66	129,79
CO2 booster + PC + ejector	90,85	94,06	108,12	108,49	107,27	111,03	113,70	119,39	119,61	126,27	124,21	128,44	126,44
Subcritical CO2 booster with R513A cycle	93,89	97,46	112,14	114,80	115,04	115,10	119,43	122,28	125,14	128,13	129,57	130,79	131,56
Subcritical CO2 booster + PC with R513A cycle	92,29	95,35	109,00	110,21	108,95	111,67	115,39	118,44	121,09	123,89	125,13	126,44	127,06

Assumptions

GWP is obtained using the 5th AR IPCC (2013)

GWP_{100} (CO_2): 1
GWP_{100} (R513A): 574.24

Cascade R513A / CO_2:
HFC Charge: 400 kg
CO_2 Charge: 80 kg

CO_2 *booster*:
CO_2 Charge: 400 kg

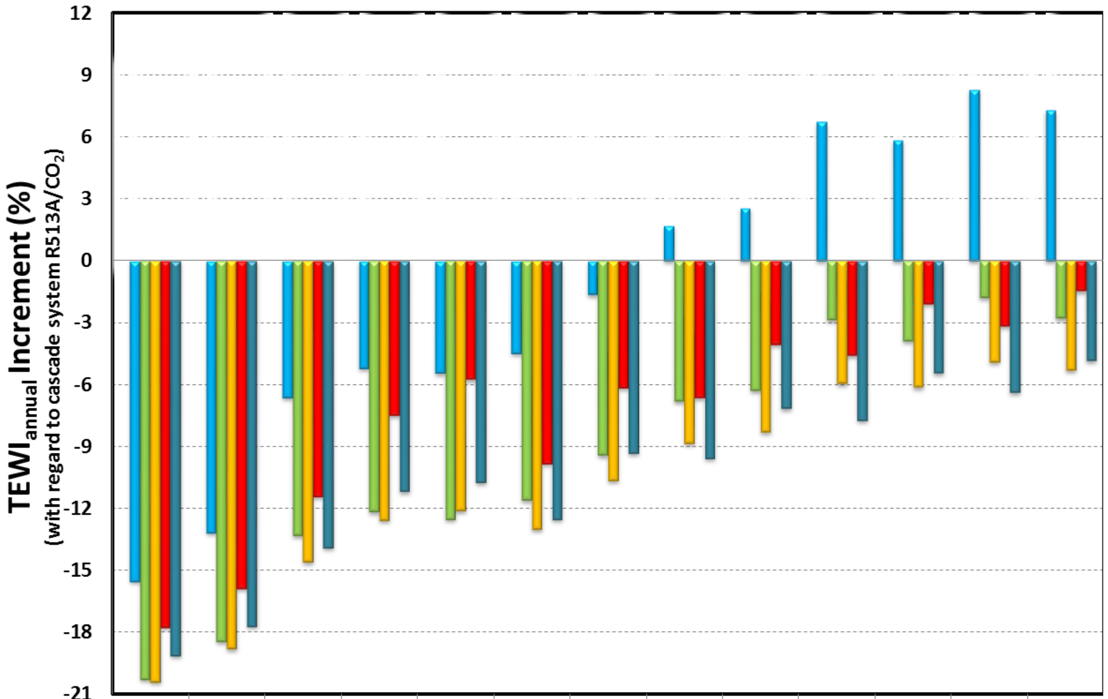
Subcritical CO_2 booster:
HFC Charge: 80 kg
CO_2 Charge: 400 kg

Energy conversion factor obtained from IDAE (2012) :
0.3 tn eq. CO_2 / MW·h

Annual Leakage obtained from MERCADONA (2016):
5 %

Alternative commercial refrigeration systems

Annual TEWI



	Burgos	León	Huesca	Bilbao	La Coruña	Madrid	Barcelona	Cáceres	Valencia	Córdoba	Málaga	Sevilla	Almería
Annual Average Temperature (ºC)	9,89	10,75	13,40	14,03	14,12	14,31	15,34	16,17	16,74	17,45	17,96	18,21	18,51
CO2 booster	-15,53	-13,17	-6,63	-5,22	-5,47	-4,49	-1,65	1,70	2,56	6,72	5,85	8,29	7,30
CO2 booster + Parallel compressor (PC)	-20,28	-18,46	-13,32	-12,17	-12,53	-11,61	-9,44	-6,82	-6,29	-2,89	-3,89	-1,79	-2,80
CO2 booster + PC + ejector	-20,41	-18,81	-14,61	-12,58	-12,12	-13,03	-10,66	-8,85	-8,31	-5,97	-6,15	-4,92	-5,31
Subcritical CO2 booster with R513A cycle	-17,74	-15,88	-11,43	-7,49	-5,76	-9,84	-6,16	-6,65	-4,06	-4,59	-2,10	-3,18	-1,48
Subcritical CO2 booster + PC with R513A cycle	-19,14	-17,70	-13,91	-11,19	-10,75	-12,53	-9,33	-9,58	-7,17	-7,75	-5,46	-6,40	-4,85

Assumptions

GWP is obtained using the 5th AR IPCC (2013)

GWP_{100} (CO_2): 1
GWP_{100} (R513A): 574.24

Cascade R513A / CO_2:
HFC Charge: 400 kg
CO_2 Charge: 80 kg

CO_2 *booster*:
CO_2 Charge: 400 kg

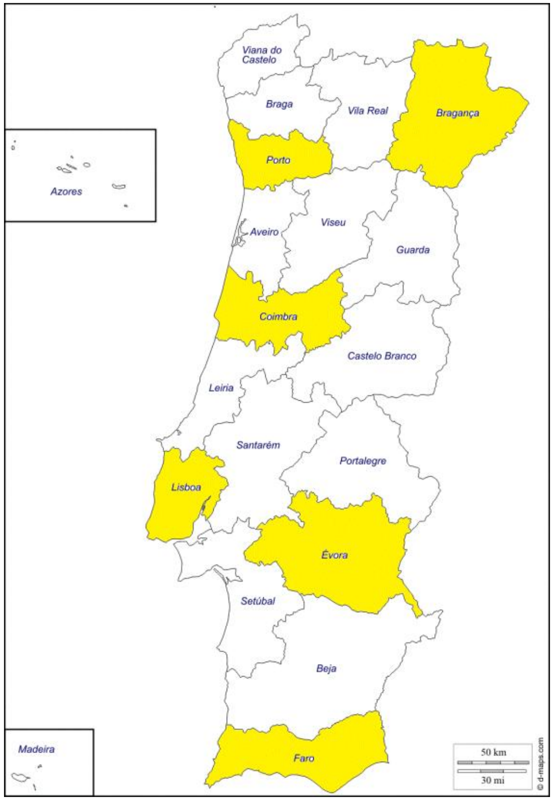
Subcritical CO_2 booster:
HFC Charge: 80 kg
CO_2 Charge: 400 kg

Energy conversion factor obtained from IDAE (2012) :
0.3 tn eq. CO_2 / MW·h

Annual Leakage obtained from MERCADONA (2016):
5 %

Alternative commercial refrigeration systems

Energy Consumption



Country: **Portugal**

<u>Cooling Load Demand Profile</u>

100% → 7 am – 22 pm

50% → rest of the day

<u>Temperature Profile</u>

Software *EnergyPlus* (2016)

<u>Positive Temperature</u>

140 kW

-8 ºC in cascade system

-6ºC in *booster* CO_2 systems

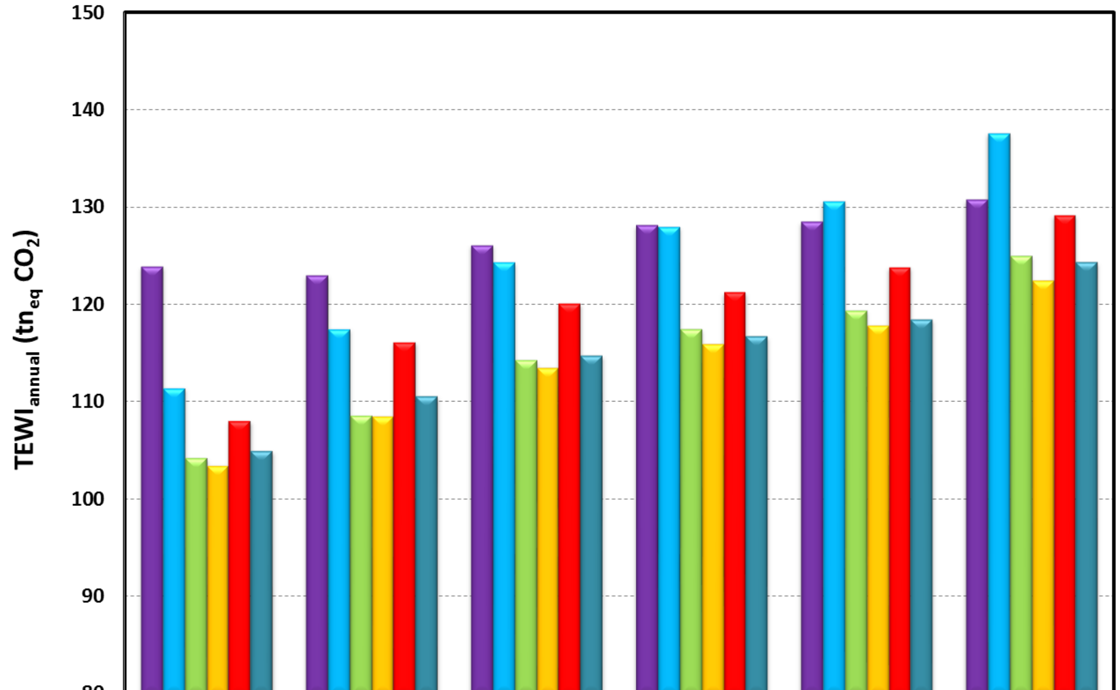
<u>Negative Temperature</u>

41 kW

-32 ºC in both cycles

Alternative commercial refrigeration systems

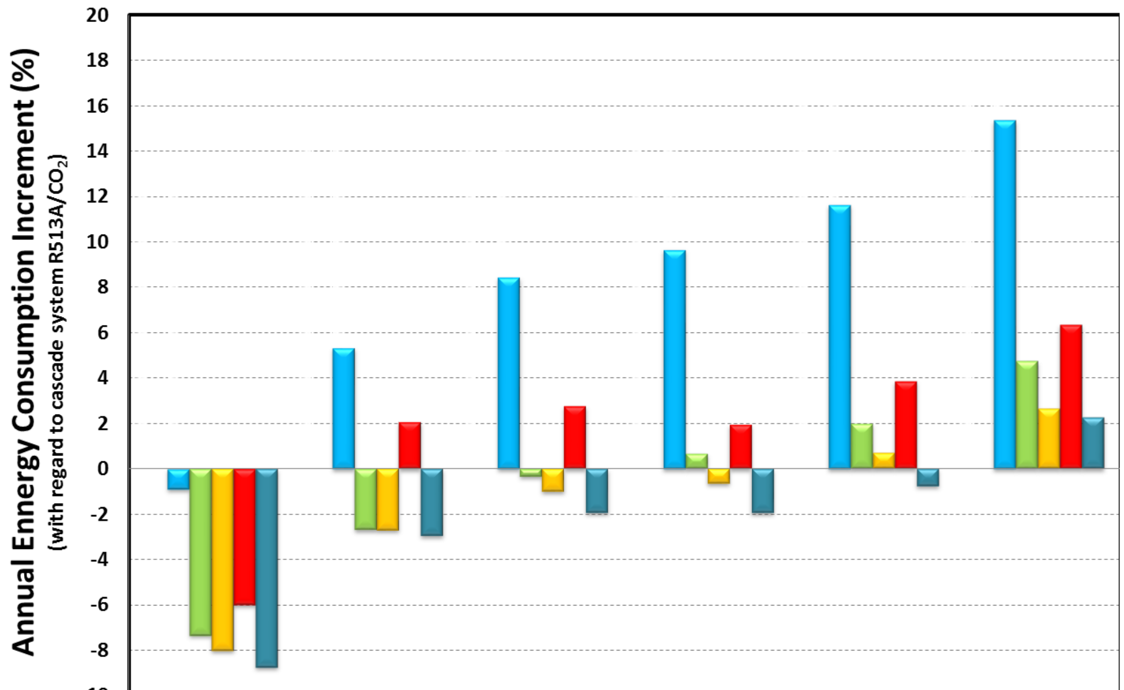
Energy Consumption



	Bragança	Oporto	Coimbra	Évora	Lisboa	Faro
Cascade R513A / R744	123,92	123,01	126,11	128,15	128,49	130,77
CO2 booster	111,45	117,50	124,33	127,97	130,65	137,61
CO2 booster + Parallel compressor (PC)	104,22	108,56	114,28	117,46	119,37	124,97
CO2 booster + PC + ejector	103,46	108,54	113,52	115,95	117,86	122,47
Subcritical CO2 booster with R513A cycle	108,03	116,15	120,12	121,25	123,86	129,19
Subcritical CO2 booster + PC with R513A cycle	104,93	110,56	114,74	116,72	118,45	124,33

Alternative commercial refrigeration systems

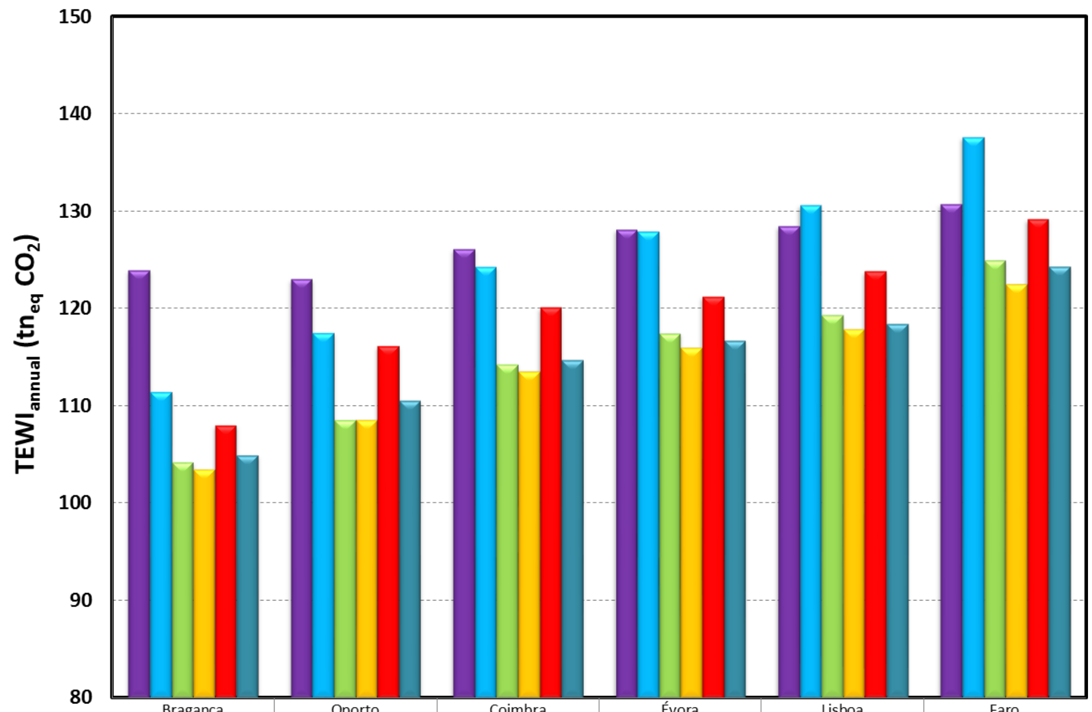
Energy Consumption



	Bragança	Oporto	Coimbra	Évora	Lisboa	Faro
Annual Average Temperature (ºC)	12,37	14,30	15,32	15,78	16,29	17,73
CO2 booster	-0,89	5,34	8,45	9,68	11,64	15,36
CO2 booster + Parallel compressor (PC)	-7,32	-2,68	-0,32	0,67	2,01	4,76
CO2 booster + PC + ejector	-8,00	-2,69	-0,98	-0,63	0,71	2,66
Subcritical CO2 booster with R513A cycle	-5,98	2,07	2,77	1,95	3,88	6,37
Subcritical CO2 booster + PC with R513A cycle	-8,73	-2,94	-1,92	-1,93	-0,74	2,29

Alternative commercial refrigeration systems

Annual TEWI



	Bragança	Oporto	Coimbra	Évora	Lisboa	Faro
Cascade R513A / R744	123,92	123,01	126,11	128,15	128,49	130,77
Classical CO2 booster	111,45	117,50	124,33	127,97	130,65	137,61
Classical CO2 booster + Parallel compressor (PC)	104,22	108,56	114,28	117,46	119,37	124,97
Classical CO2 booster + PC + ejector	103,46	108,54	113,52	115,95	117,86	122,47
Subcritical CO2 booster with R513A cycle	108,03	116,15	120,12	121,25	123,86	129,19
Subcritical CO2 booster + PC with R513A cycle	104,93	110,56	114,74	116,72	118,45	124,33

Assumptions

GWP is obtained using the 5th AR IPCC (2013)

GWP_{100} (CO_2): 1
GWP_{100} (R513A): 574.24

Cascade R513A / CO_2:
HFC Charge: 400 kg
CO_2 Charge: 80 kg

CO_2 *booster*:
CO_2 Charge: 400 kg

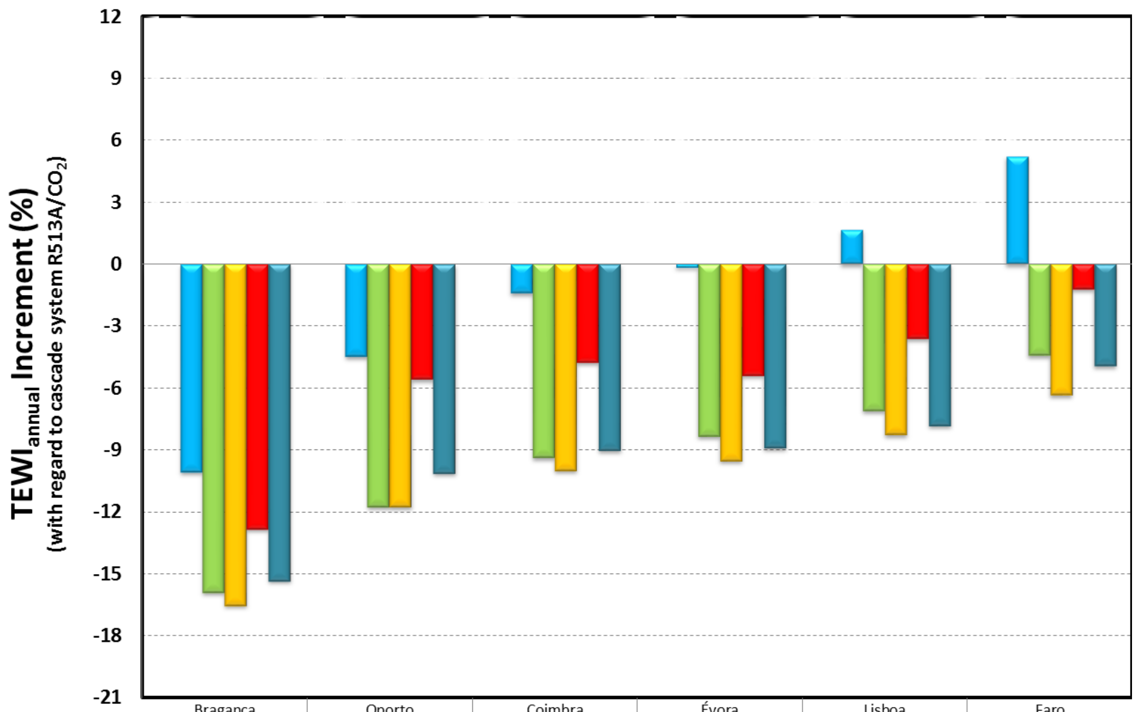
Subcritical CO_2 booster:
HFC Charge: 80 kg
CO_2 Charge: 400 kg

Energy conversion factor obtained from IDAE (2012) :
0.3 tn eq. CO_2 / MW·h

Annual Leakage obtained from MERCADONA (2016):
5 %

Alternative commercial refrigeration systems

Annual TEWI



	Bragança	Oporto	Coimbra	Évora	Lisboa	Faro
Annual Average Temperature (ºC)	12,37	14,30	15,32	15,78	16,29	17,73
CO2 booster	-10,07	-4,48	-1,41	-0,14	1,68	5,24
CO2 booster + Parallel compressor (PC)	-15,90	-11,75	-9,38	-8,34	-7,10	-4,43
CO2 booster + PC + ejector	-16,51	-11,76	-9,99	-9,52	-8,28	-6,34
Subcritical CO2 booster with R513A cycle	-12,83	-5,58	-4,75	-5,38	-3,61	-1,21
Subcritical CO2 booster + PC with R513A cycle	-15,32	-10,12	-9,02	-8,91	-7,81	-4,92

Assumptions

GWP is obtained using the 5th AR IPCC (2013)

GWP_{100} (CO_2): 1
GWP_{100} (R513A): 574.24

Cascade R513A / CO_2:
HFC Charge: 400 kg
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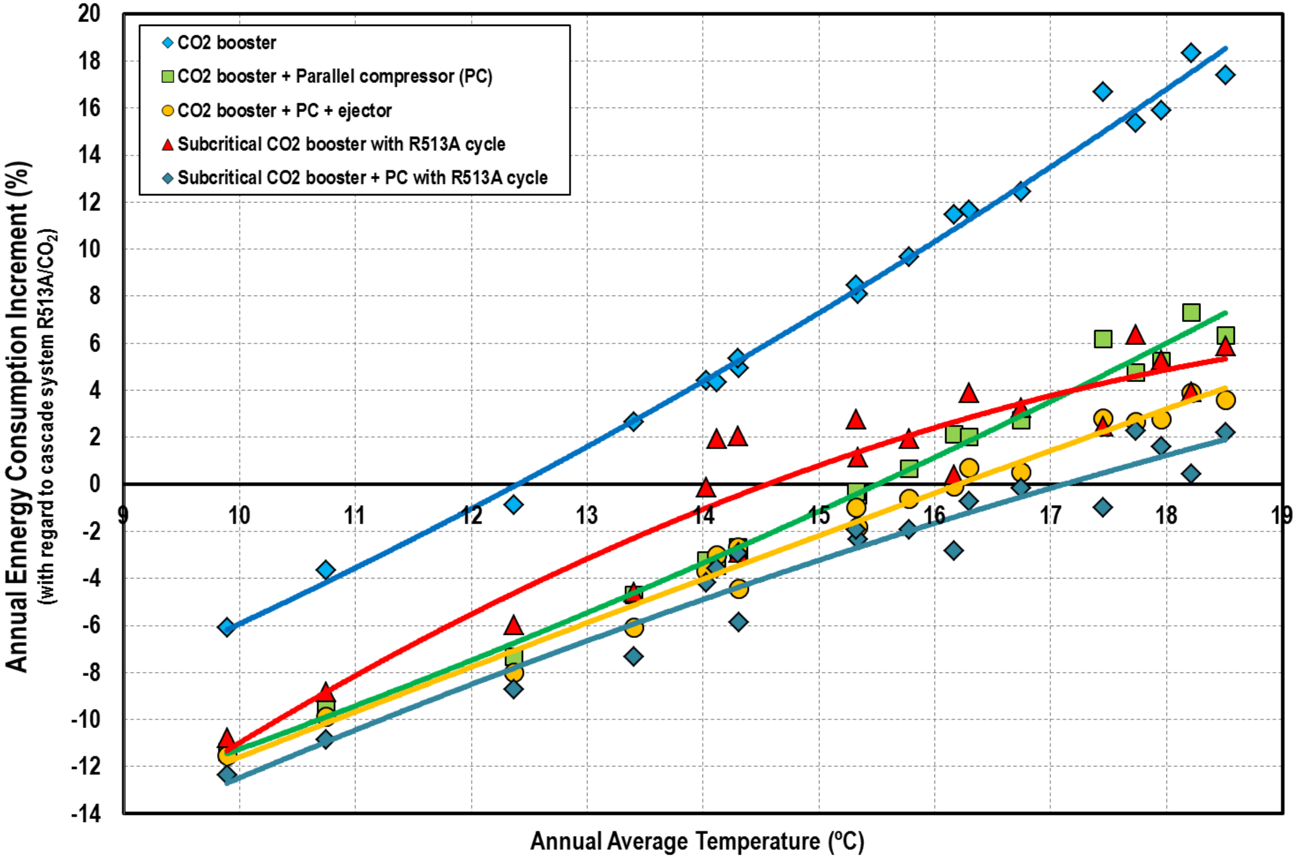
Energy conversion factor obtained from IDAE (2012) :
0.3 tn eq. CO_2 / MW·h

Annual Leakage obtained from MERCADONA (2016):
5 %

Alternative commercial refrigeration systems

Energy Consumption



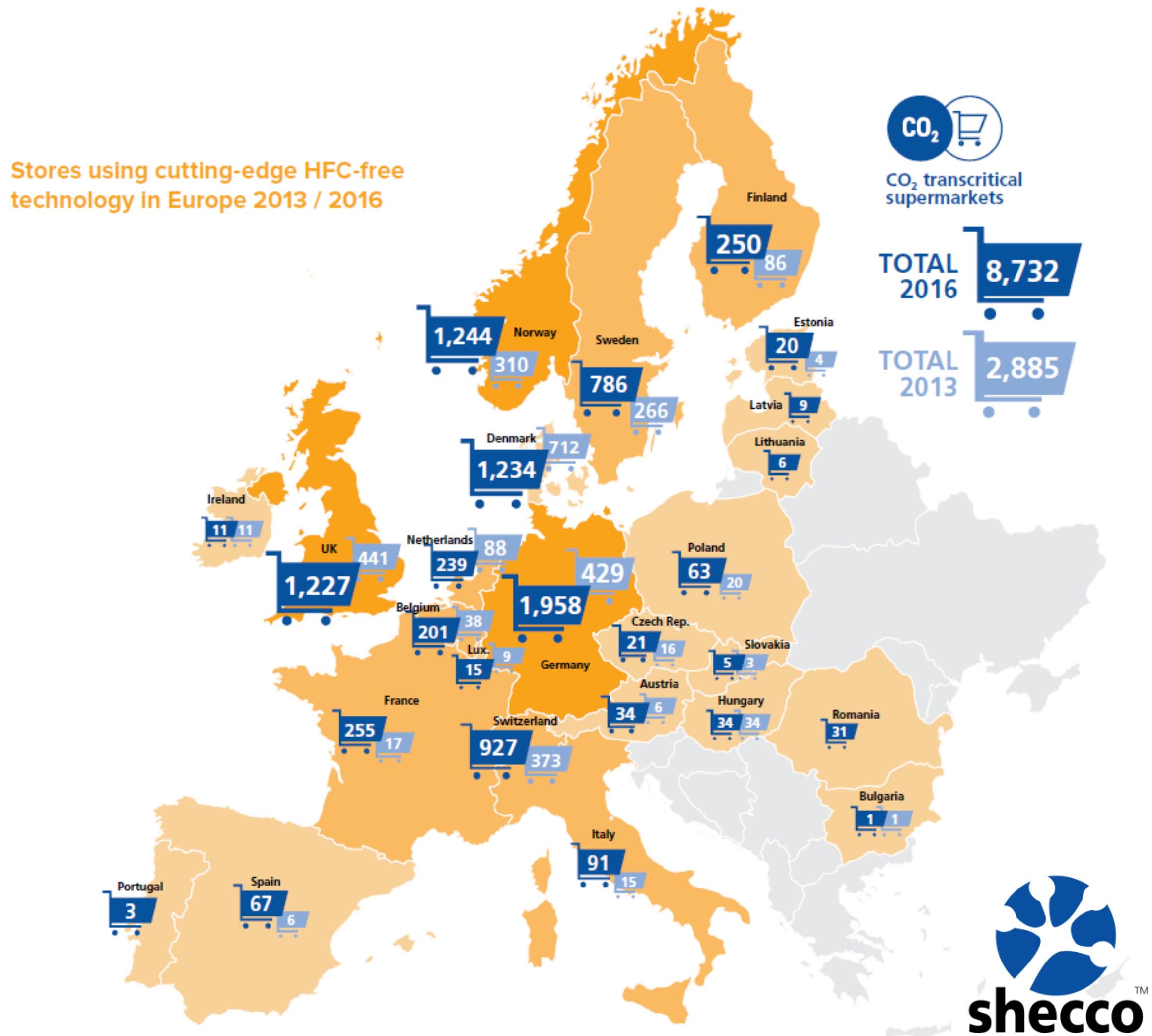
Alternative commercial refrigeration systems

<u>What about Europe?</u>

Low annual average temperatures at North and Central Europe justify the use of basic CO_2 *booster* systems.

Germany, Denmark, Norway, UK, and Switzerland represent the **75.47%** of the total supermarkets installed in Europe with *booster* CO_2 technology.

Spain, Portugal and Italy they only represent the **1.84 %** .



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