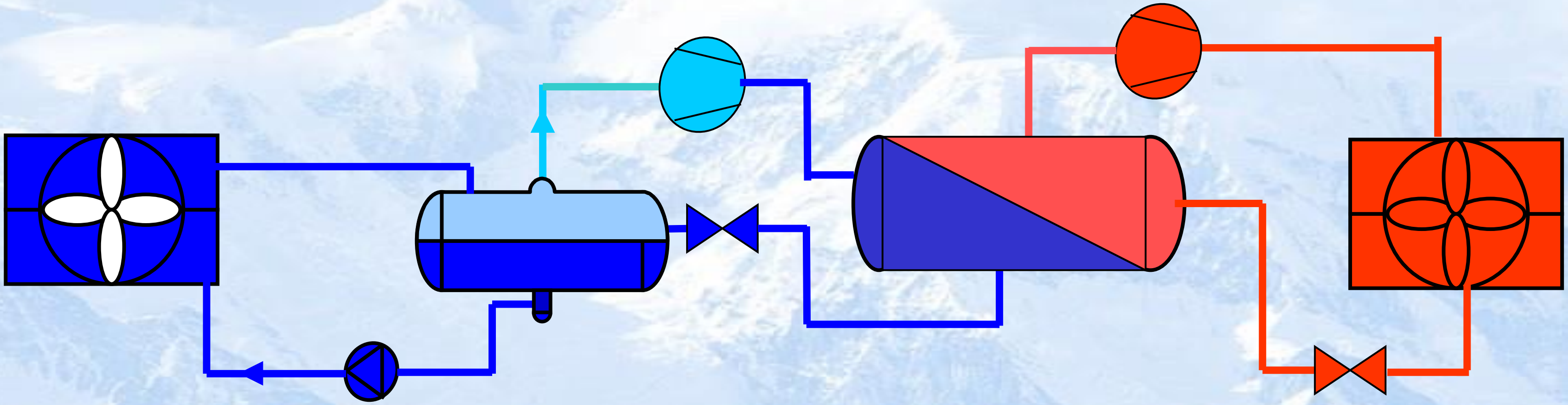
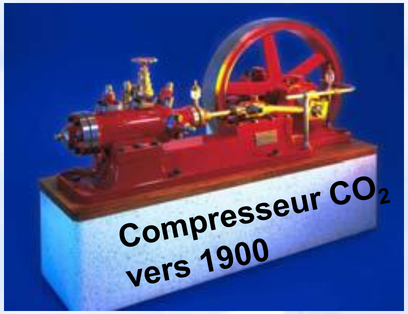
CO2 refrigeration and Its applications



Benoit Rodier, P.Eng.

TOROMONT CIMCO

History of CO_2



Peak period of CO_2

Transcritical Cycle CO_2

First usage of CO_2 as a refrigerant (Alexander Twining ,British patent)

J&E Hall first CO_2 two stage system

CFC introduction 1928

Reintroduction of CO2 in refrigération

(G. Lorentzen)Norvège

Montreal Protocole

1er jan. 1989

1850

1920 ----------1930

1960

1993

First CO_2 refrigeration system
Carle Linde

Danfoss ,***Niels P Vestergaard Niels P Vestergaard*** *Ver 2004-04-SI+US*

Thermodynamic Properties

CO_2 (Carbon Dioxide / R744)

- CO2 is present in the atmosphere in an proportion approximate proportion of 0,0375 % in volume, during this decade (year 2000), around **375 ppmv** (parts per million in volume). Yearly concentration increase rapidly , approx **2 ppmv/year** , consequent to human activity generating green gas warming effect : Fossil fuel combustion, coal, petroleum, gas.
- CO_2 used in refrigeration is a by product of ammonia and hydrogen production process.

CO_2 as a Refrigerant

Pro

- Long tradition in Refrigeration
- Consider as a Green Refrigerant, low global warming (GWP =1)
- Chemically inert, non flammable
- Non toxic
- Volumetric capacity higher than other refrigerant
  - Subcritical: 6 to 8 times better than R22, R404A or NH_3
  - Transcritical: 4 to 5 times better than R22, R404A
- Refrigerant flow lower

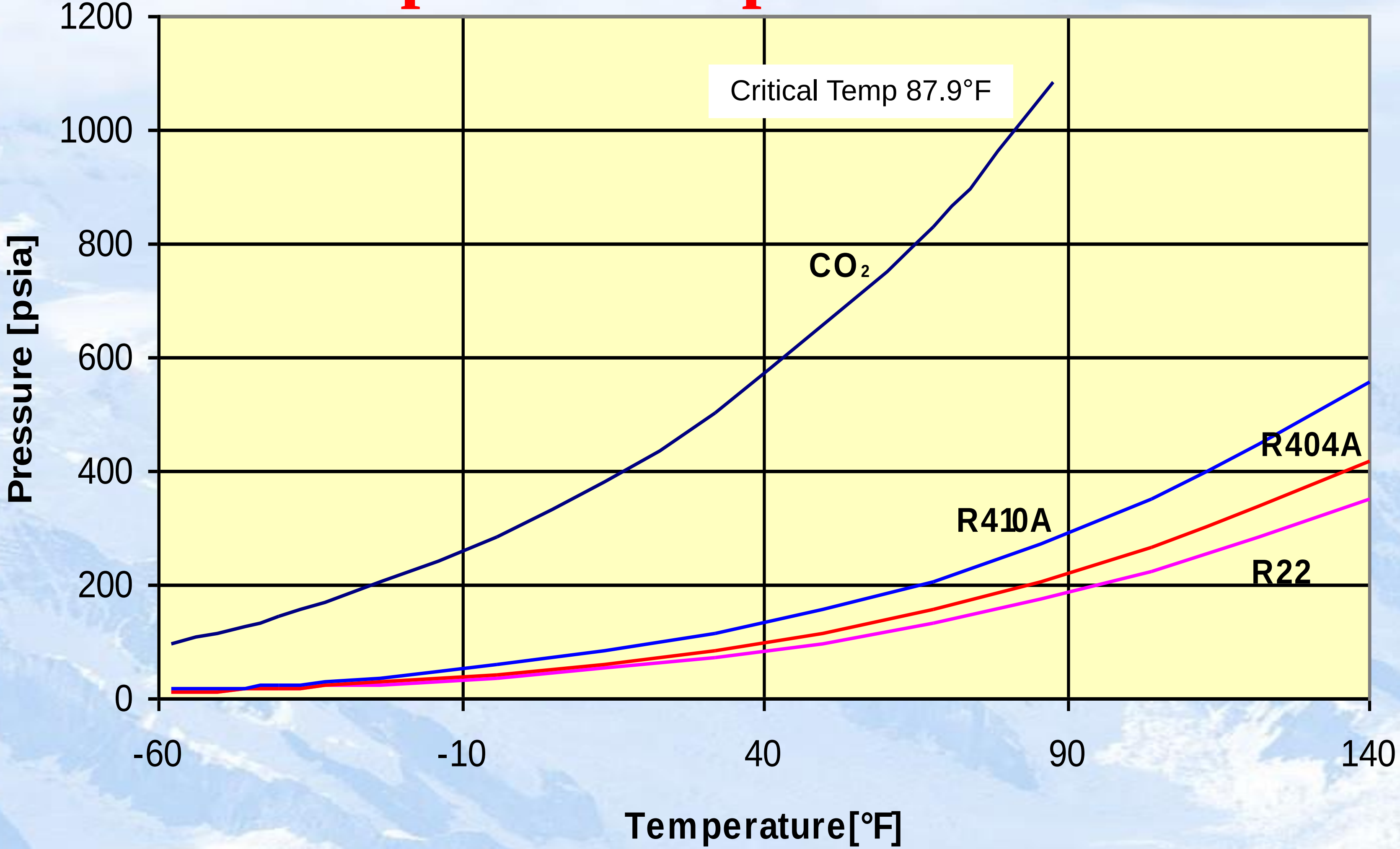
CO_2 as a Refrigerant

Cons

- Critical Temperature at 31.1°C (87.9°F)
  - Will require a trans-critical operation for single and double stage . Two stage up to 150 bar [2176psia])
  - Thermodynamic properties unfavorable for high condensing pressure / gas cooler temperature
  - High discharge pressure
  - Security rules on equipment design
- Low temperature limits (Triple point -56.6°C [-69.9°F])
- Air concentration limit lower than HFC (3.5 to 6 times less)
  - CO_2 is odorless – Requires safety measures and leaks detector in every close rooms

CO_2 as refrigerant

Comparison on pressure level



What is Sub Critical and Trans Critical ?

Sub-critical cycle

- Discharge pressure under
  - CO2 critical point

    @ 31.06 °C / 87.9°F

    73.8 bar / 1070.4 psia

- Condensation as we know it
- refrigerant ⇨ SDT < 31°C
  - Cascade system
- Condensation (ideal process)

  isobar and isotherm

Trans-critical cycle

- Discharge pressure over

  - CO2 critical point

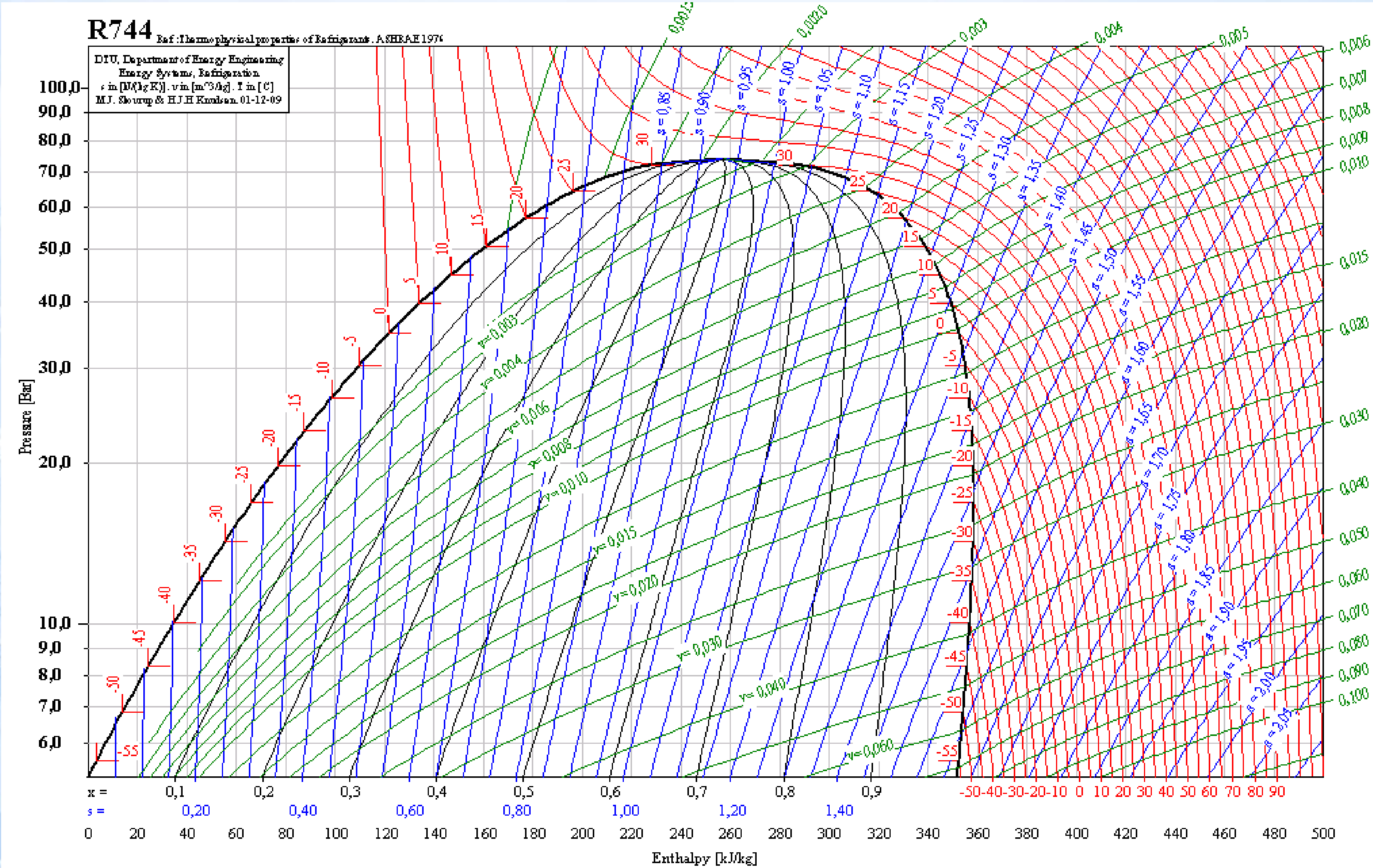
  @ 31.06 °C / 87.9°F

  73.8 bar / 1070.4 psia

- No condensation, gas cooling prior to the expansion device
- Gas cooling (ideal process

isobar , not isotherm

Log p,h-Diagram of CO_2



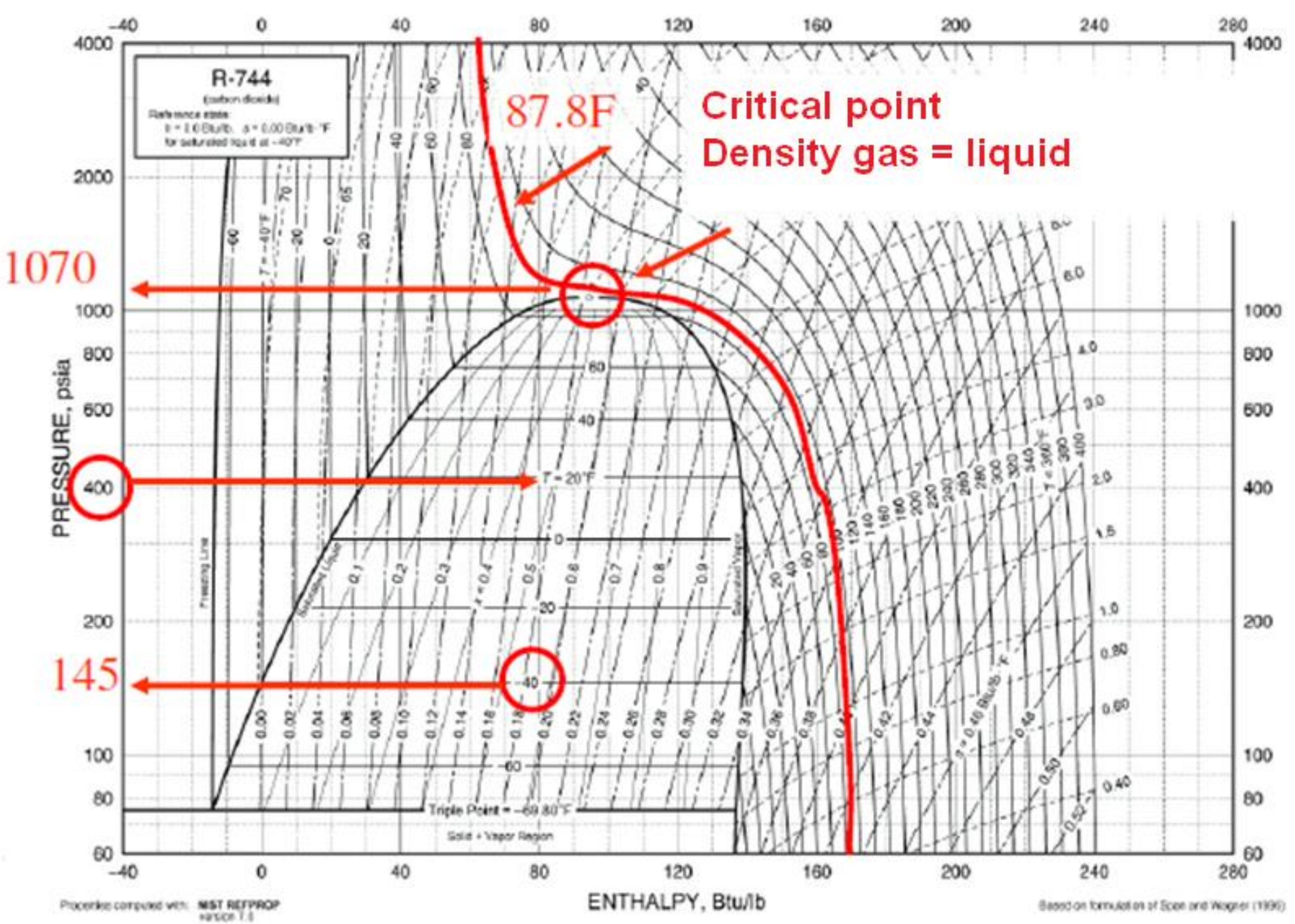
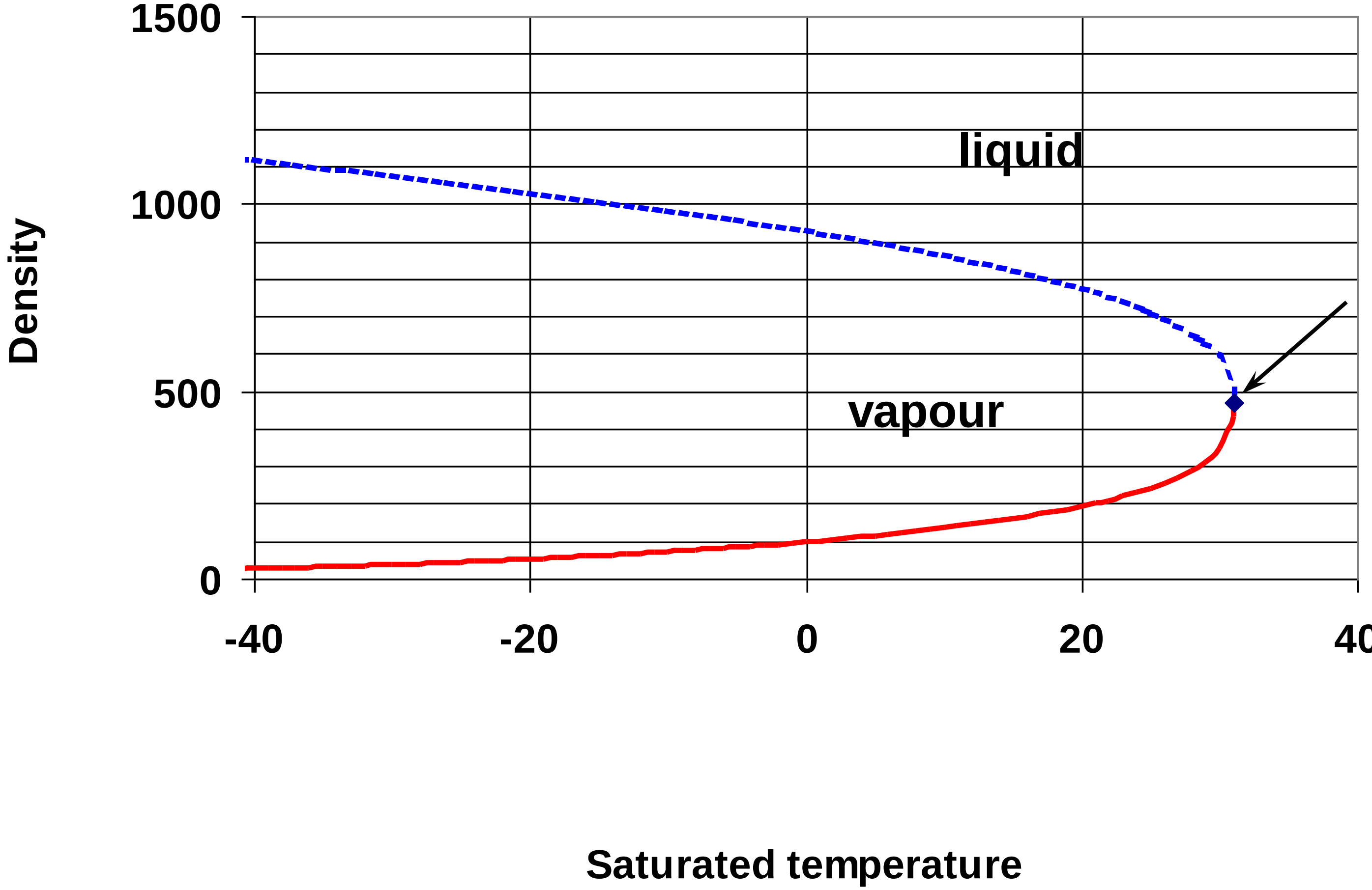


Fig. 18 Pressure-Enthalpy Diagram for Refrigerant 744 (Carbon Dioxide)

Density - CO_2 liquid / vapour

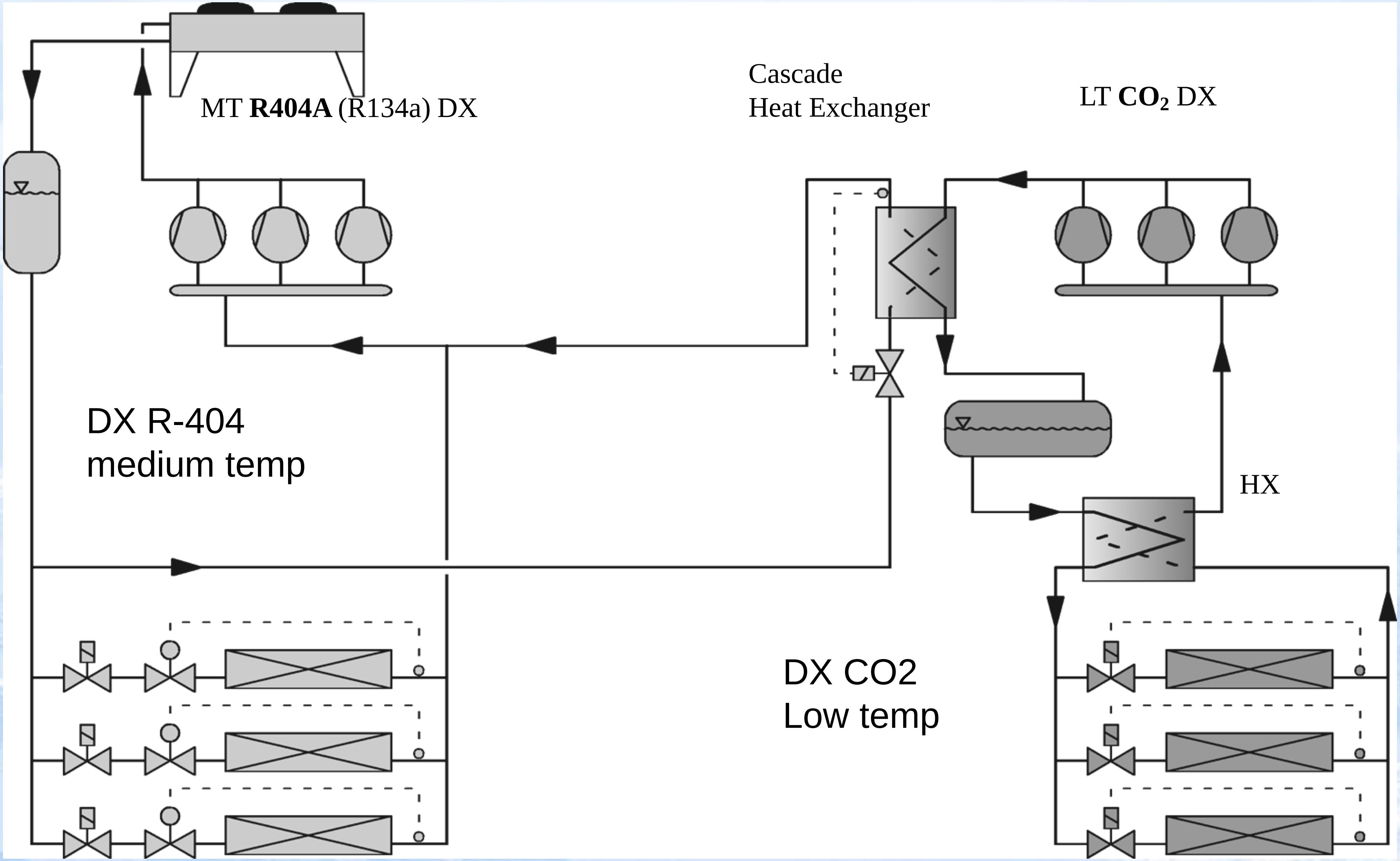


Critical point:
+31 °C [87.9 °F]
73.6 bar [1067 psi]

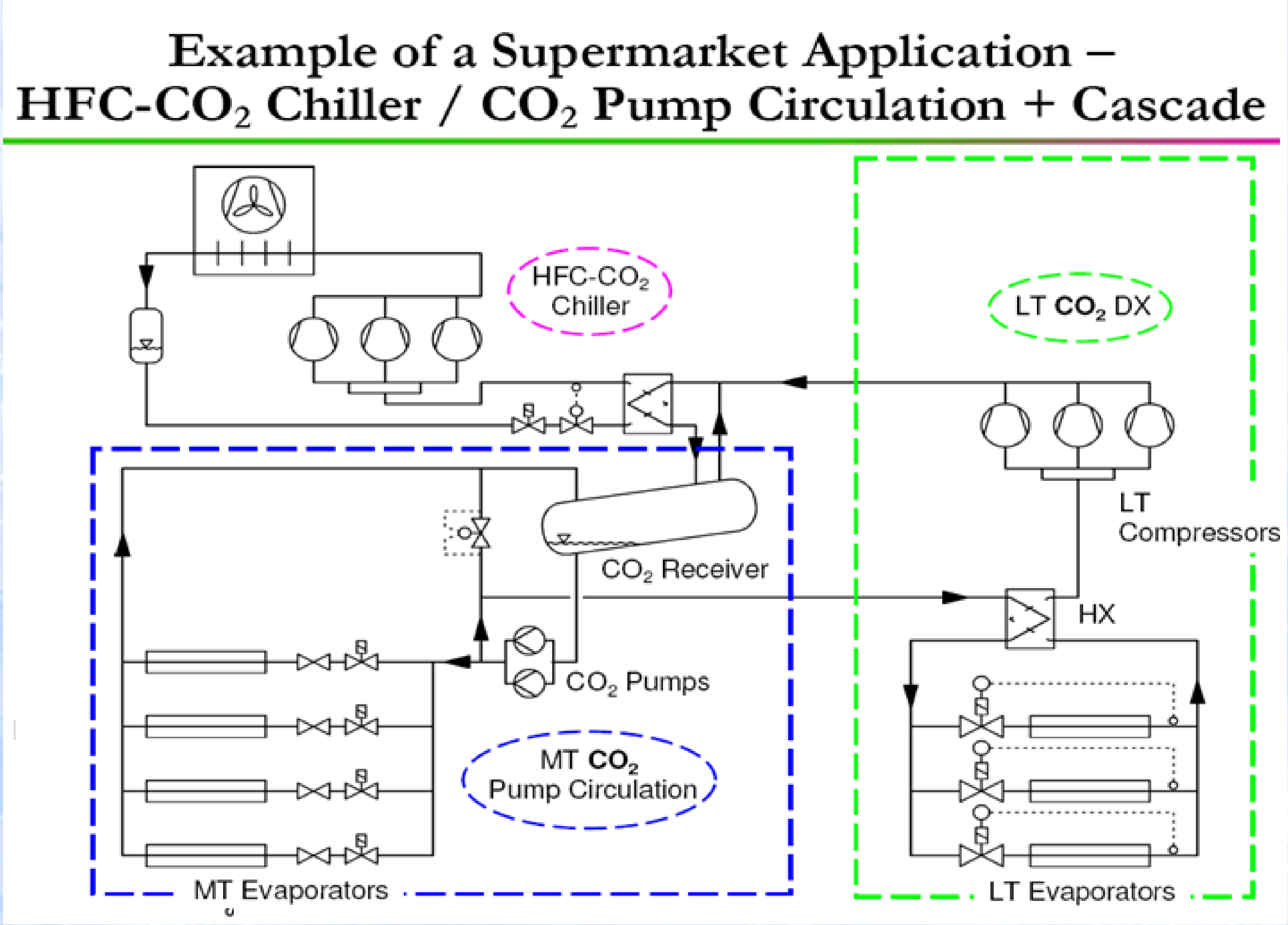
Various systems type and configurations

- Cascade system
- DX system
- Brine System
- Trans-Critical system

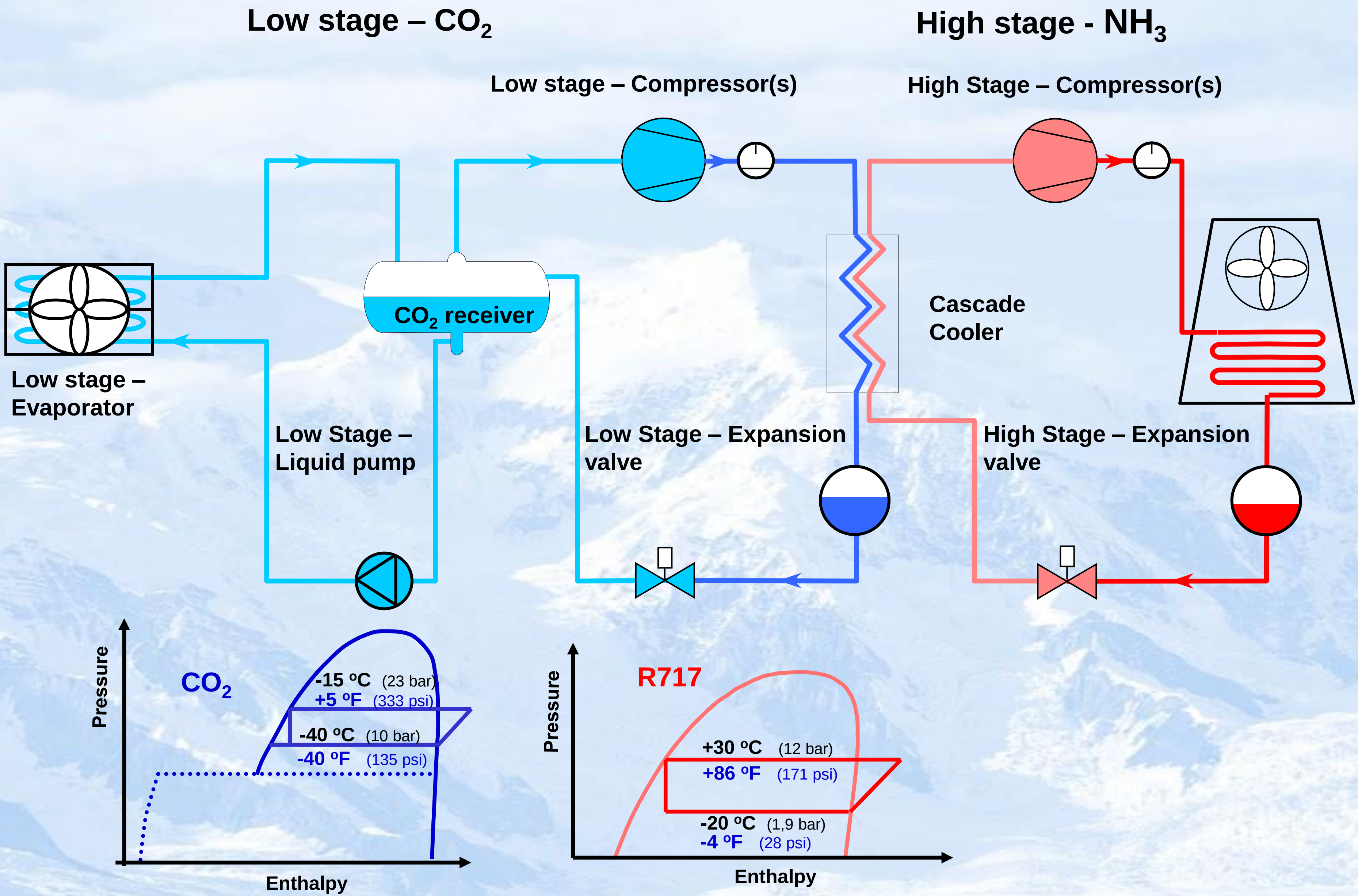
Cascade R-404A and CO2



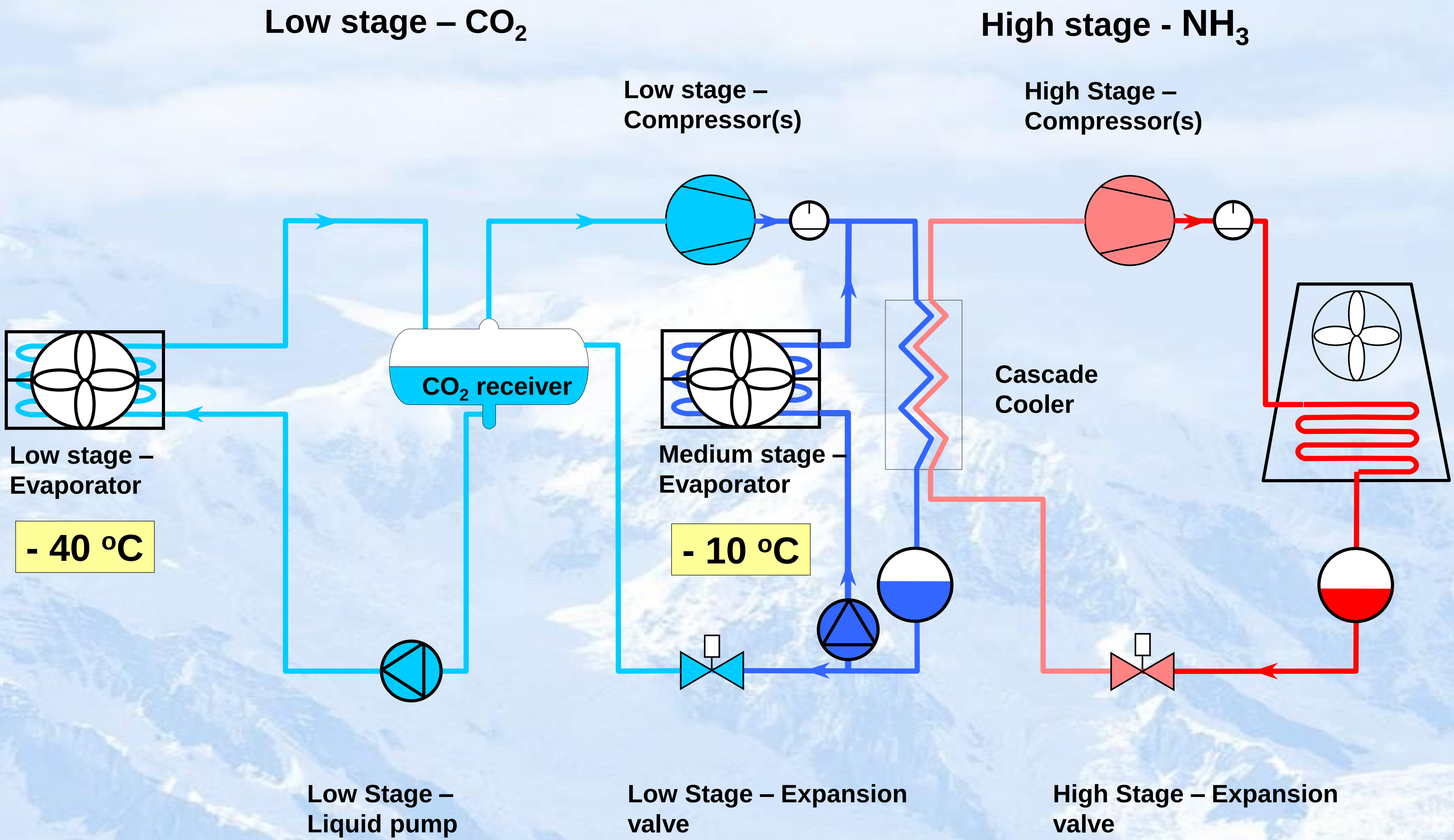
Cascade R-404A and CO2



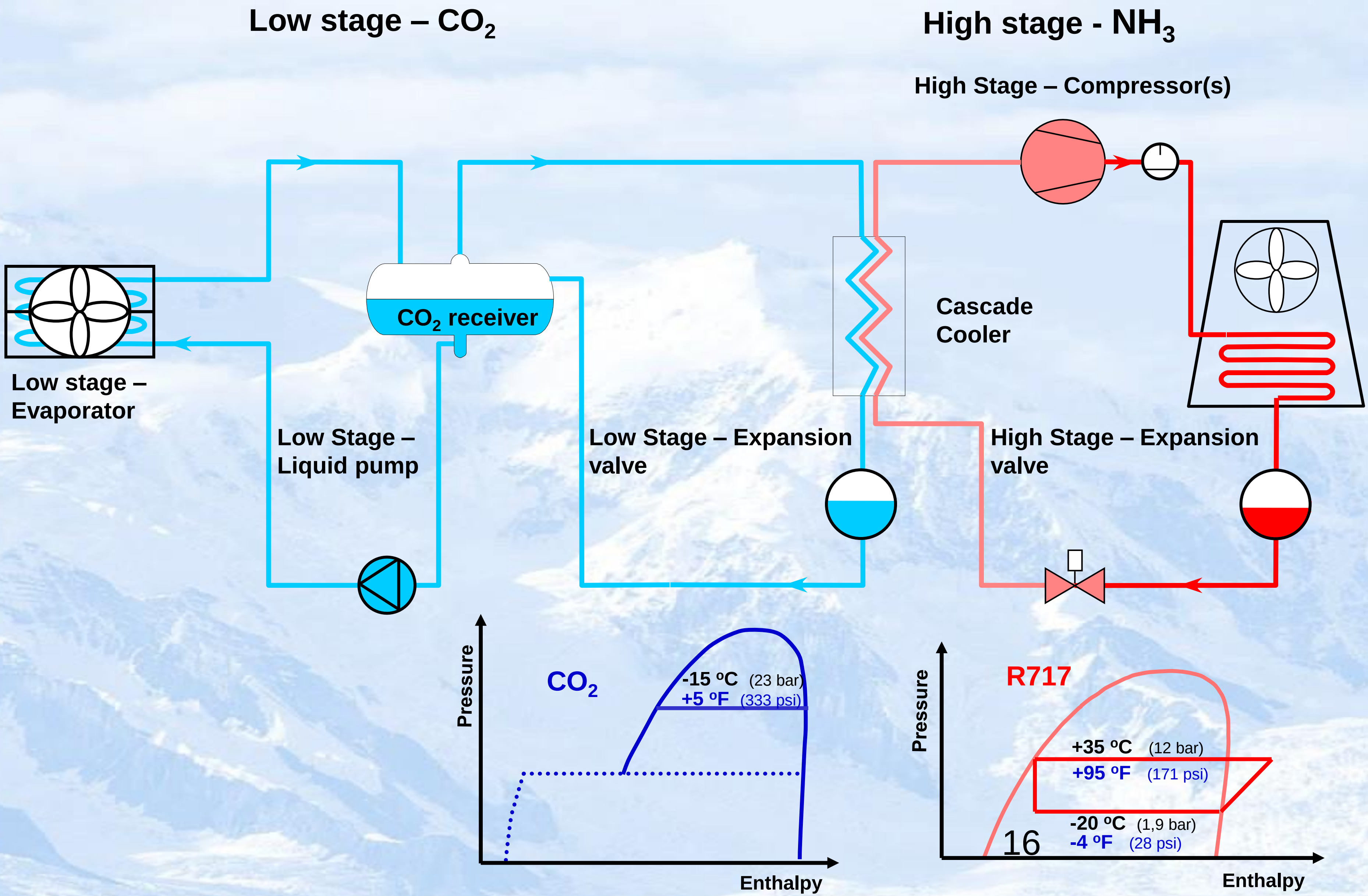
CO_2 – NH_3 cascade system



CO_2 – NH_3 cascade system

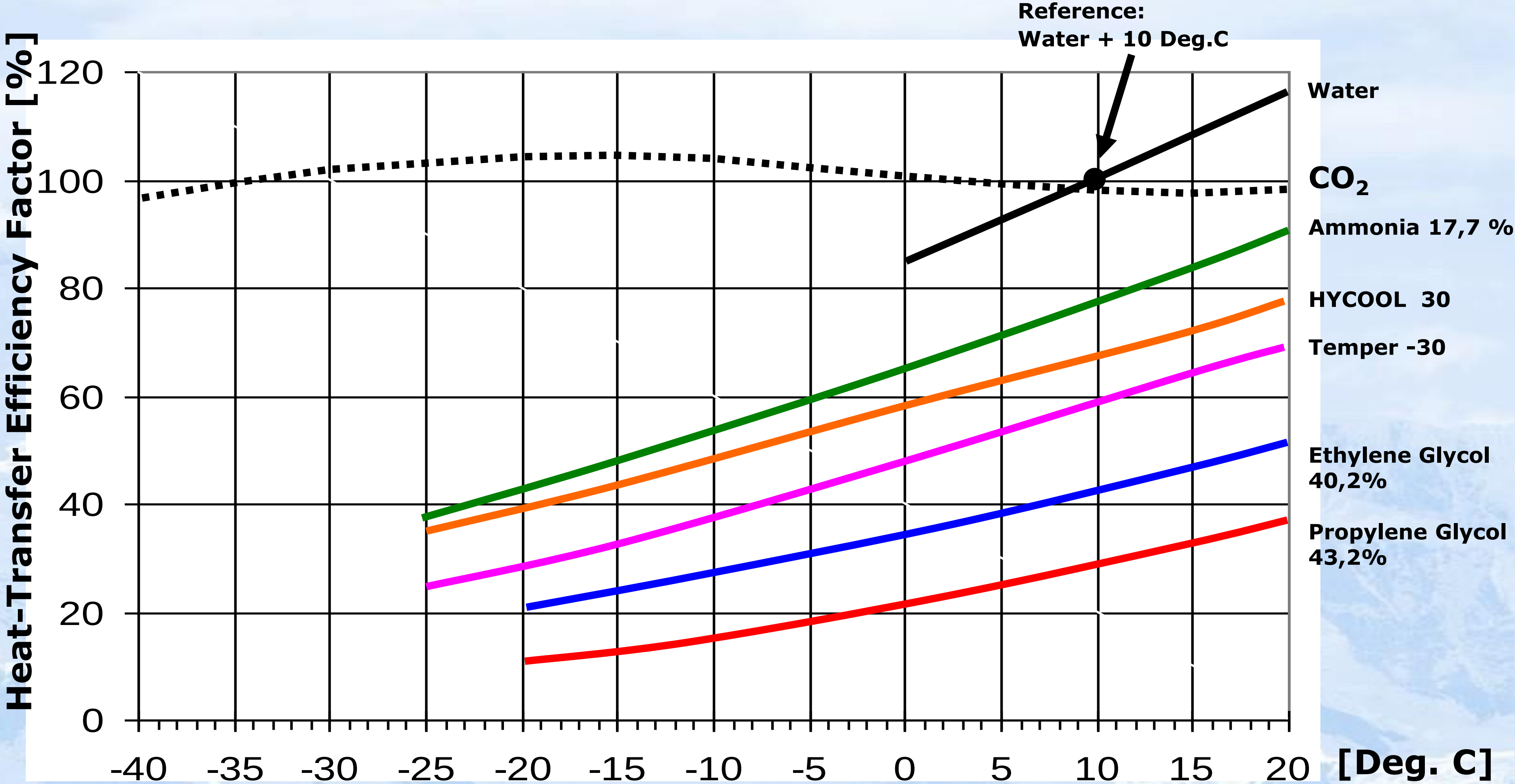


CO_2 – NH_3 "brine" system



CO2 as a brine – lower energy consumption

High Heat-Transfer Efficiency Factor



The Heat-Transfer Efficiency Factor expresses the relation between the heat-transfer coefficient and the cooler temperature.

CO_2 as a brine – lower energy consumption

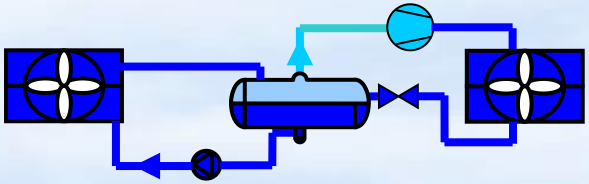
	Power, kW	
	-10^{0}C	-20^{0}C
CO_2	**0,97**	**0,85**
$CaCl_2$	**13,34**	**14,22**
Hycool	**16,02**	**16,15**
Ethylene Glycol	**14,03**	**16,68**
Propylene Glycol	**15,87**	**18,88**

- Calculated power consumption by pumps in case of ca. 500 kW capacity

Why CO_2 ?

CO2 – Drivers	**Commercial/ Supermarket**	**Industrial Refrigeration**
Environment **Phase out CFC, HCFC: Change to CO2** **(ODP** (Ozone Depletion Potential)**, GWP** (Global Warming Potential) **)**	✔	
Safety **Increased restrictions on toxic/flammable refrigerants (e.g. requirements for systems with big R717 charge)**		✔
Cost • **Reduced running cost due to increased efficiency (compressor efficiency, heat transfer)** • **Reduced cost on refrigerants.** • **Reduced size on components.**	✔	✔

Compressors Capacity



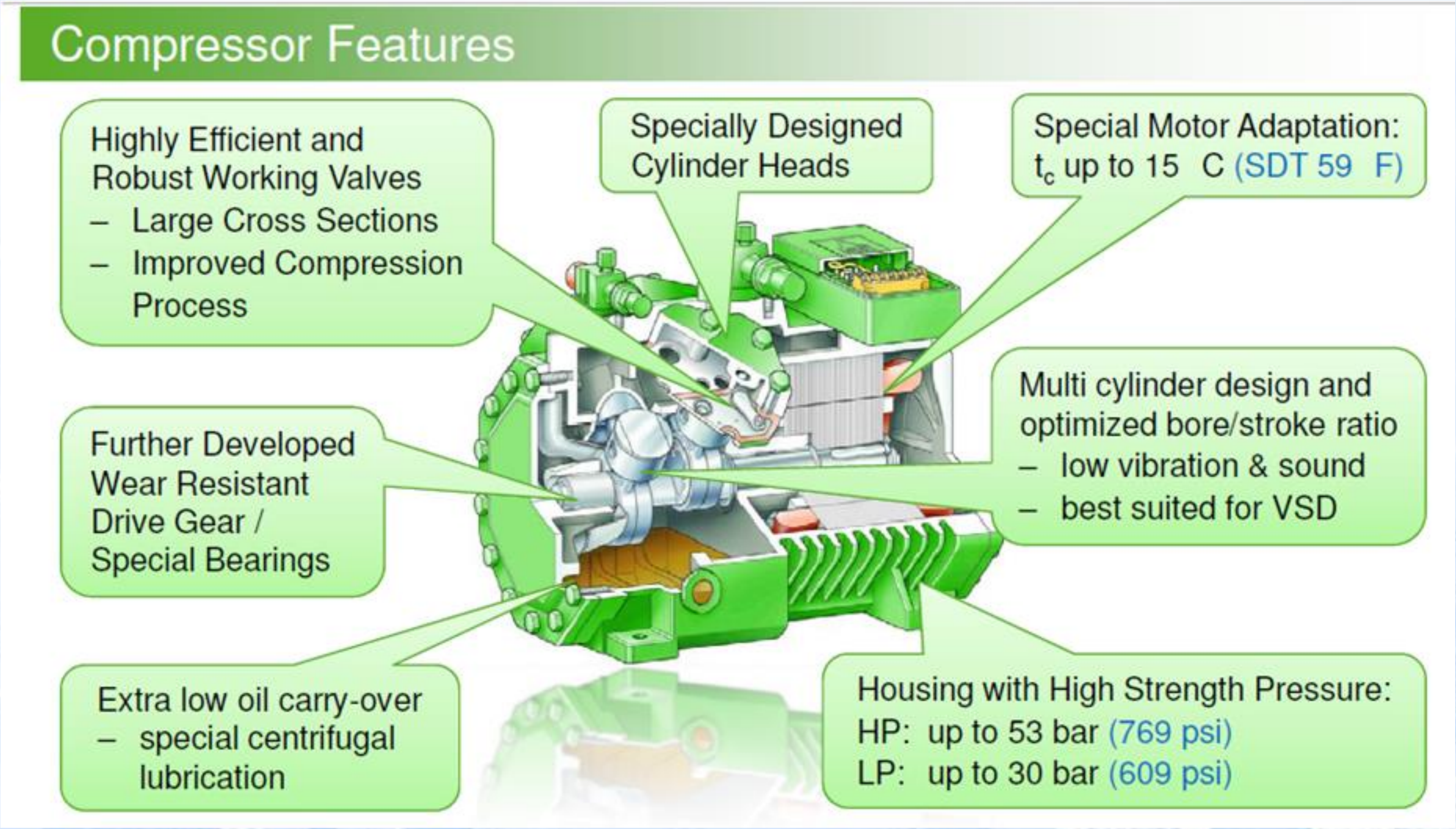
Refrigerant		R134a	R404a	R717	CO2
Cooling Load	TR	**100**	**100**	**100**	**100**
Required Compressor Displacement	CFM	**1342**	**865**	**900**	**102**
Relative Compressor capacity		***13,2***	***8.5***	***8,8***	***1,0***

Evaporating temp.: TE = -40 [Deg.F]
Condensing temp.: TC = 5 [Deg.F]

CO_2

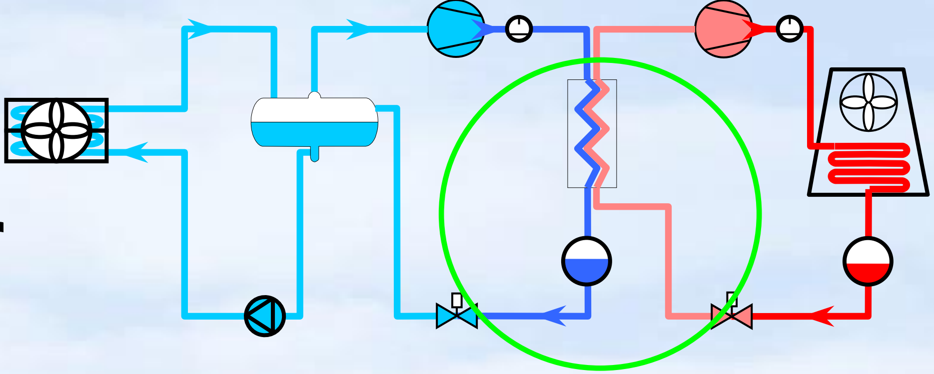
Compressors have high capacity

Compressors

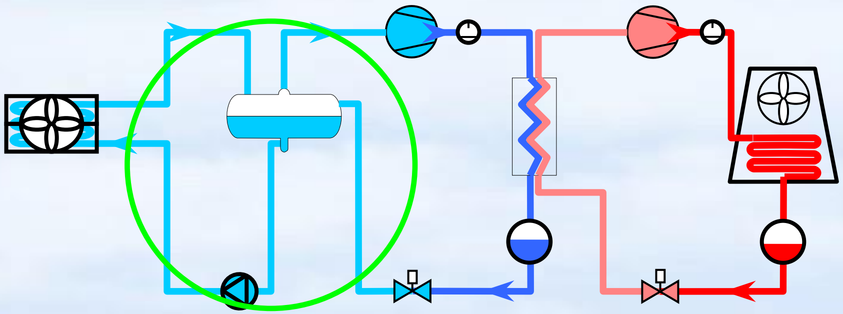


Compressors

Cascade cooler



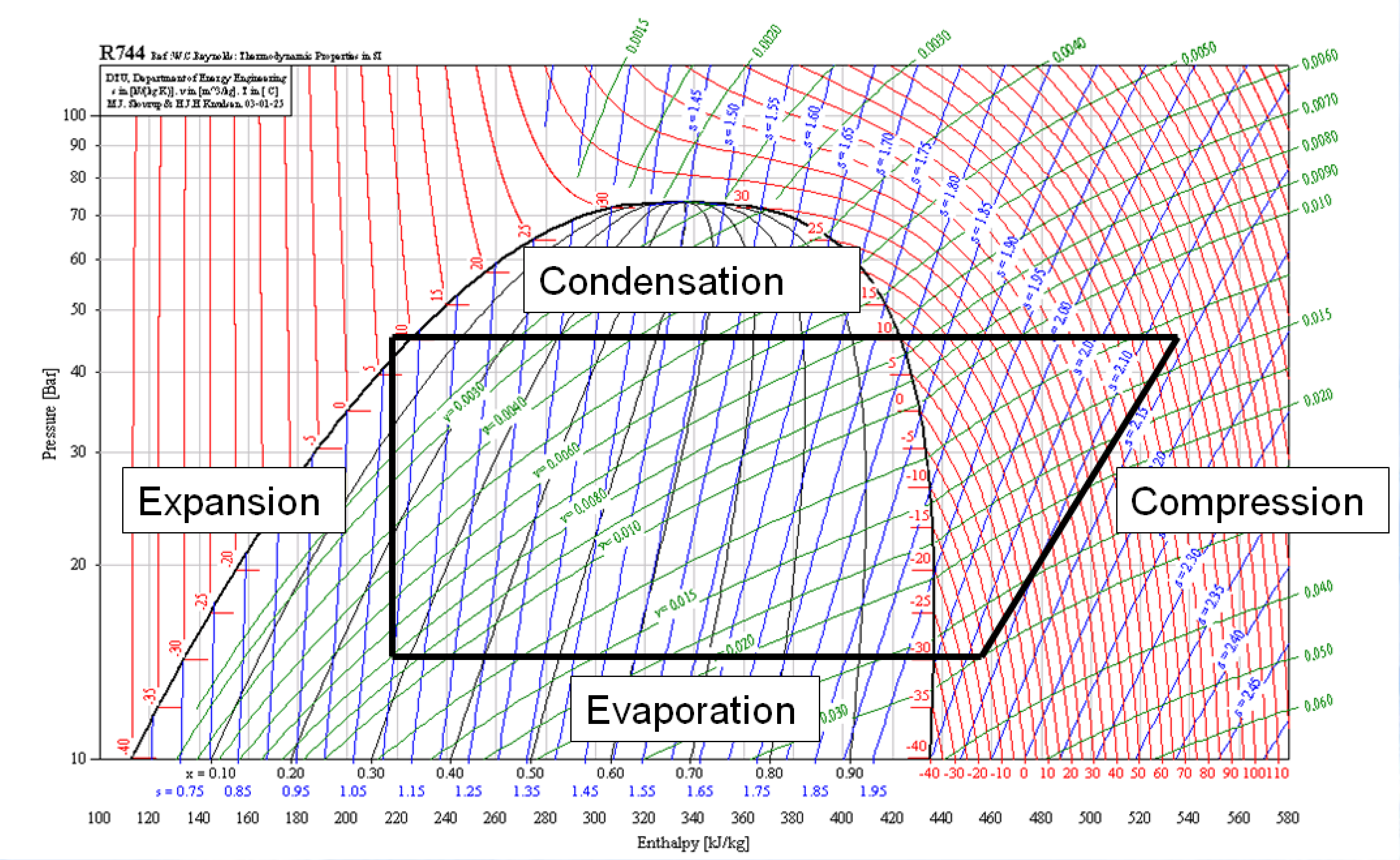
Recirculator package design



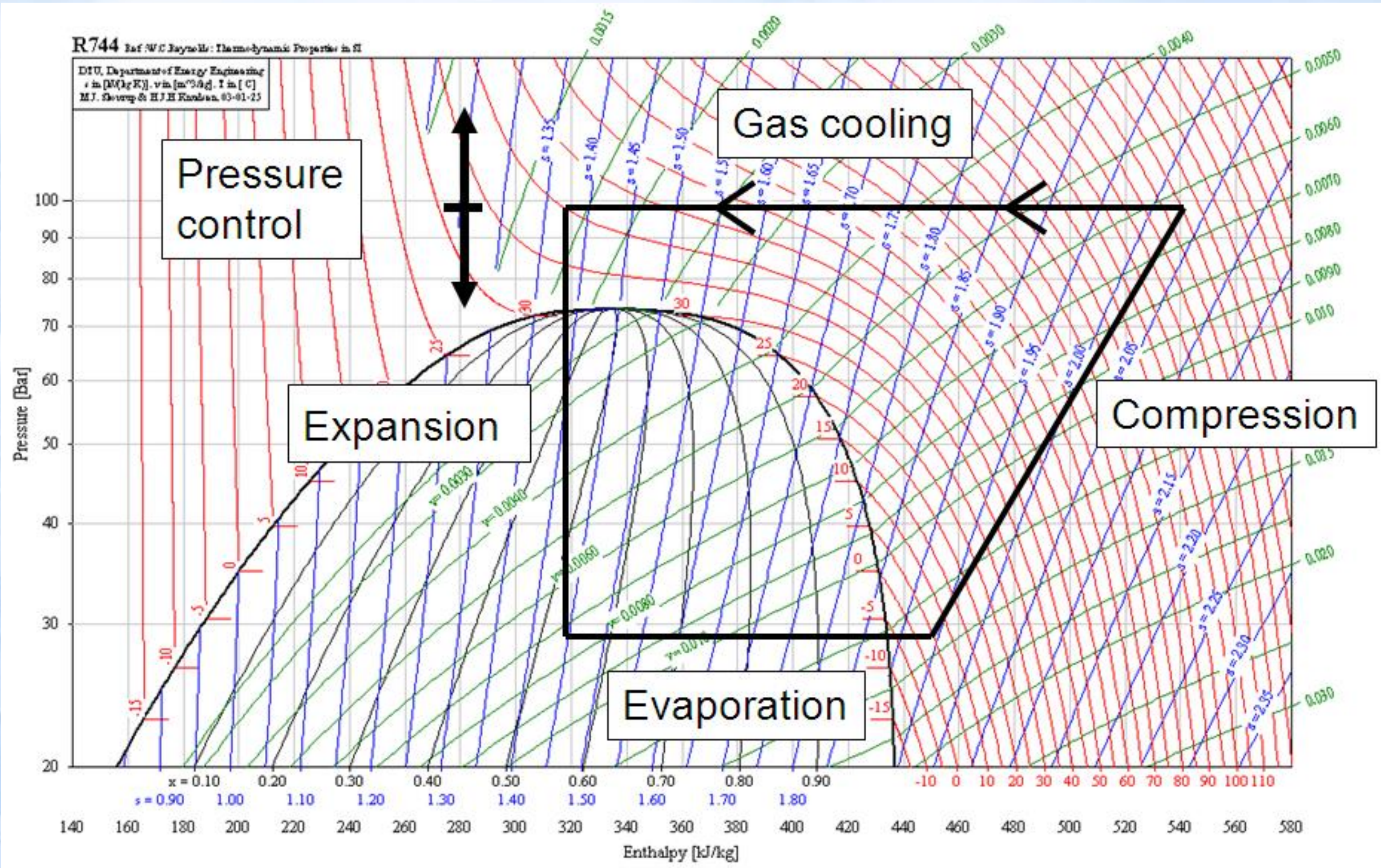
Trans-critical CO_2 System

- **Critical point CO_2 +31°C ⇒ Not possible to condense with ambient air during the whole season**
- **Gas cooler required (with optional adiabatic cooling)**
- **Gas expansion generate liquids**
- **Minimum discharge pressure of 85 b (1230 PSI) . Compressor 130 to 150 b (1845 PSI)**
- **Possible usage:**
  - **Reefer transport and containers**
  - **Heat pumps**
  - **Domestic hot water**
  - **vending machine for drinks**
  - **Automotive AC**
  - **Supermarkets and cold storage , small food plant 20 to 200kW**
  - **Condensing unit**
  - **Self contain food conter**
  - **Ice rinks**

Subcritical Refrigeration Process



Transcritical Refrigeration Process



Cycle processes with CO_2

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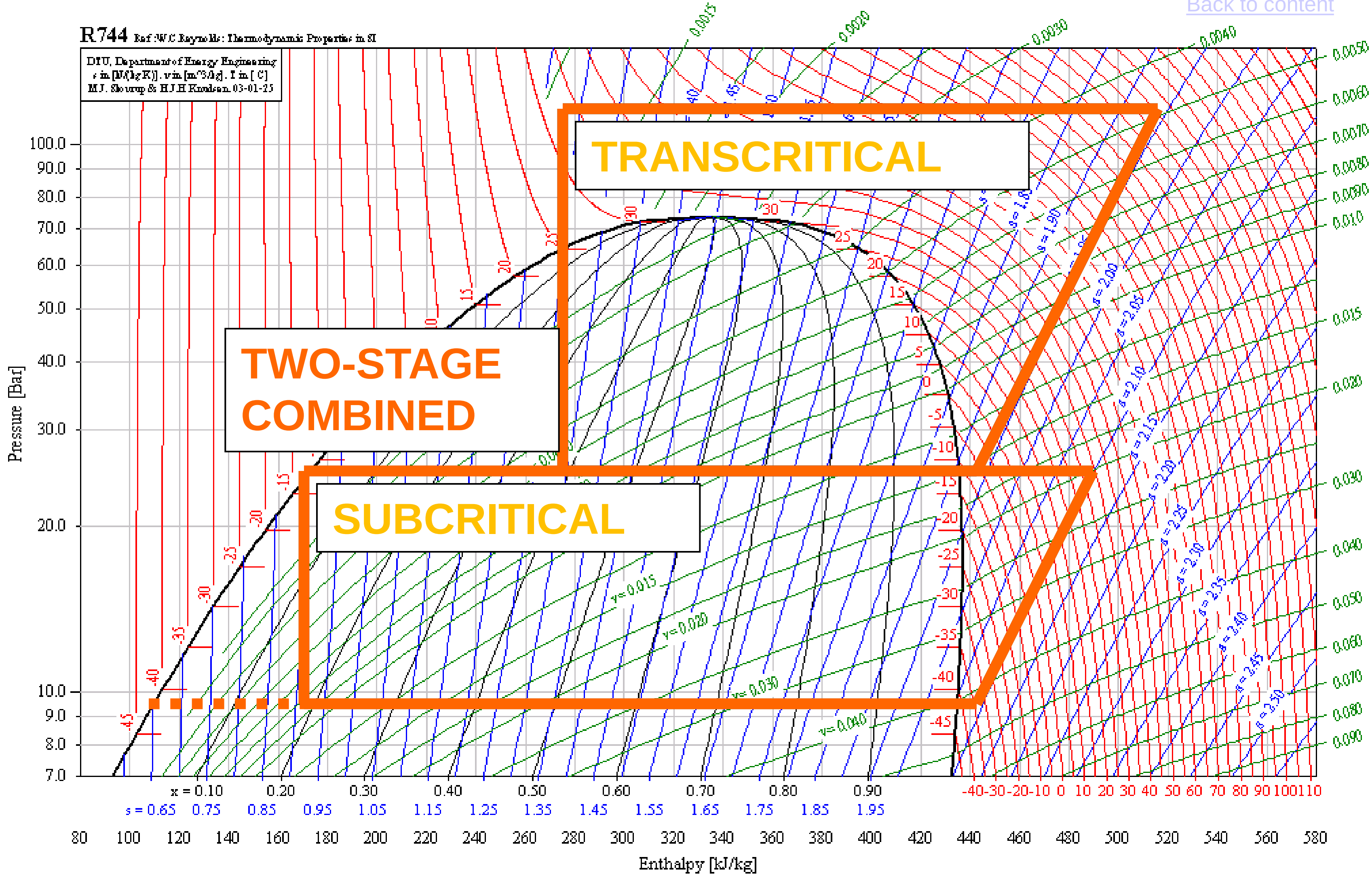

Optimal High Pressure

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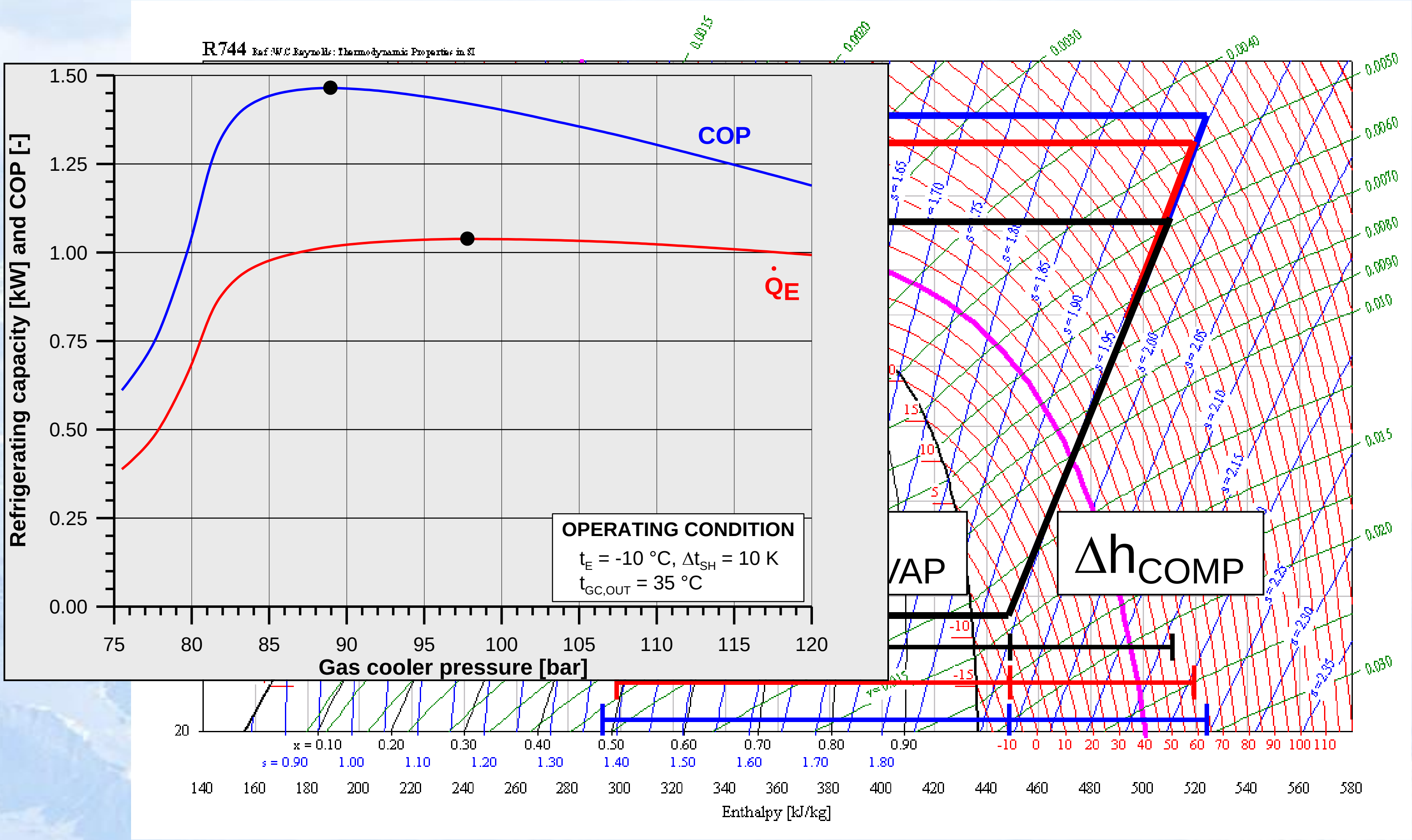
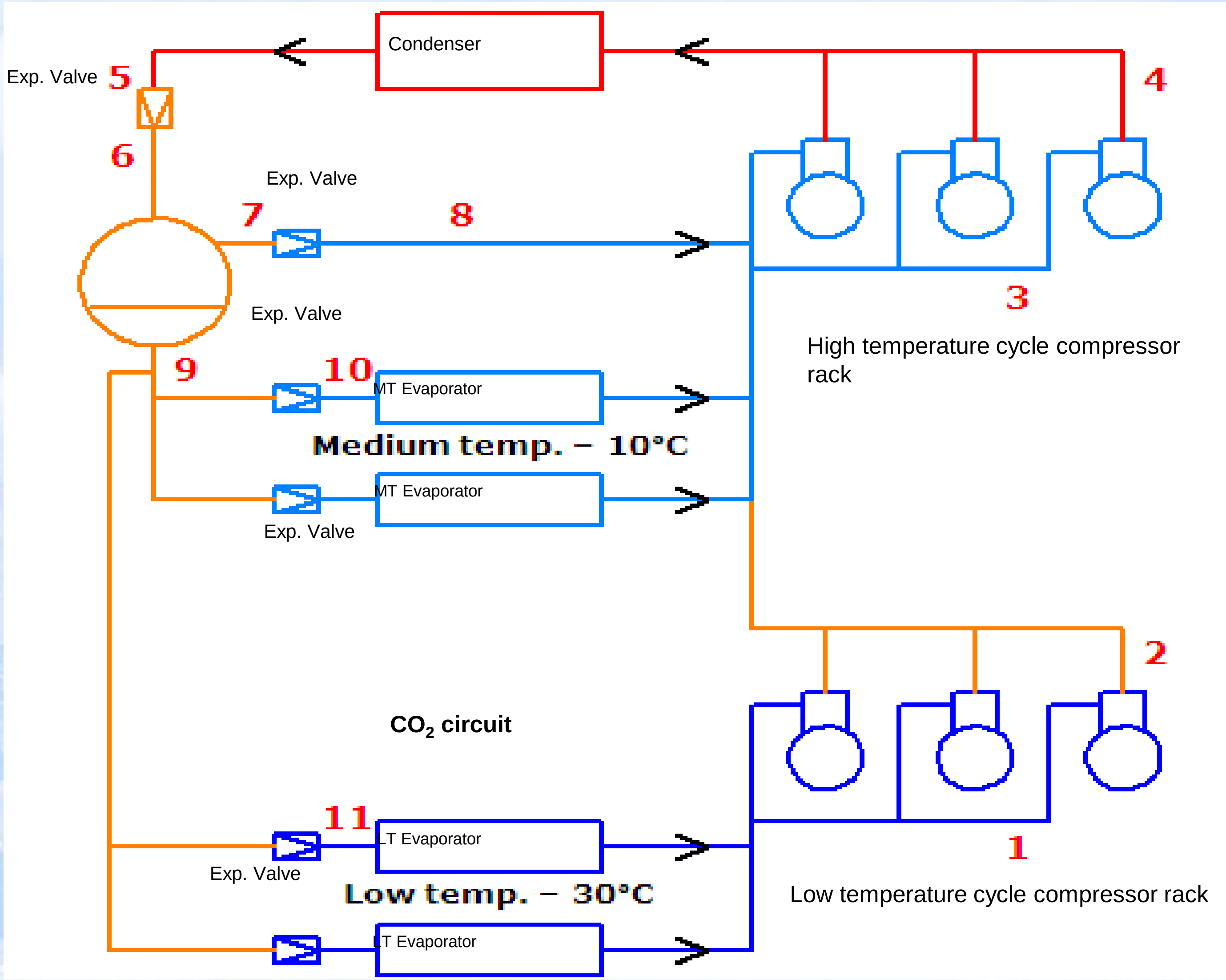
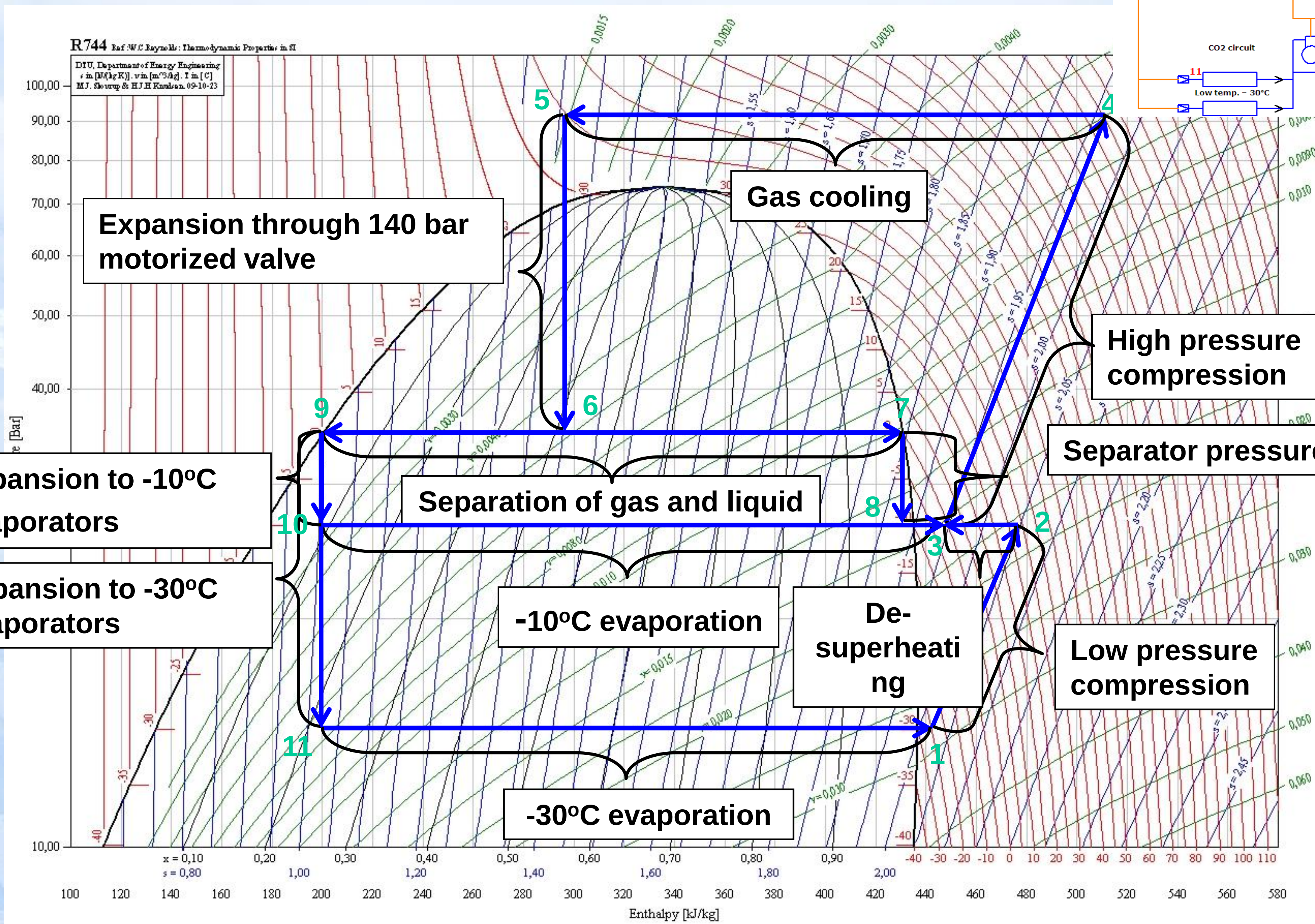
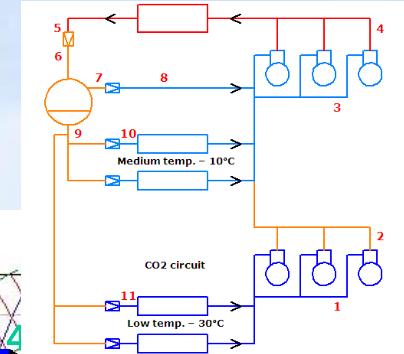


Two Stage Booster System



Two Stage Booster System - Transcritical Cycle





Two Stage Booster System
Transcriticial CO_2 Booster System

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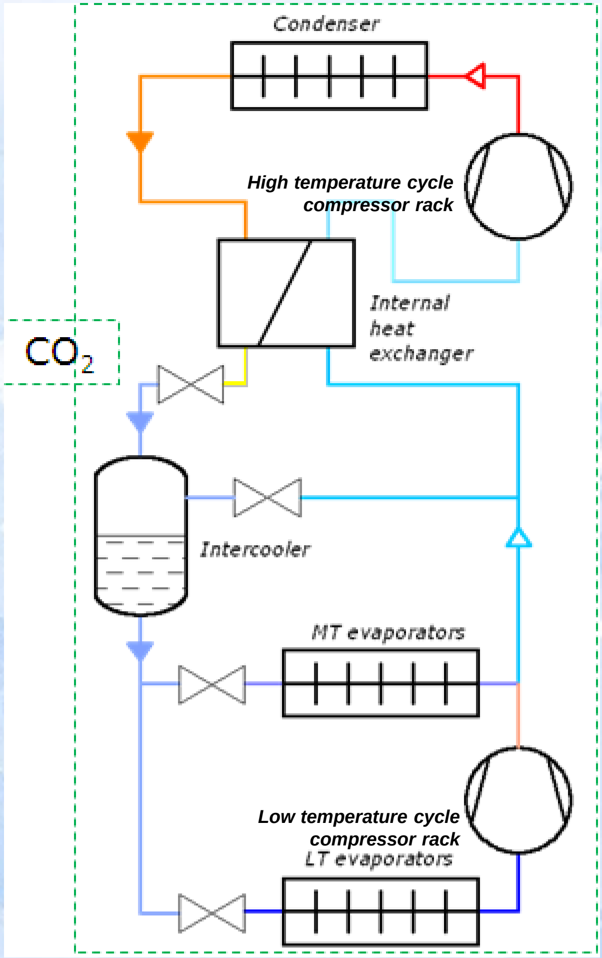


Description

- MT: CO_2 Direct expansion
- LT: CO_2 Direct expansion

Application:

FR, server cooling, heat pump, Ice rinks, selected I.R plants

Benefits

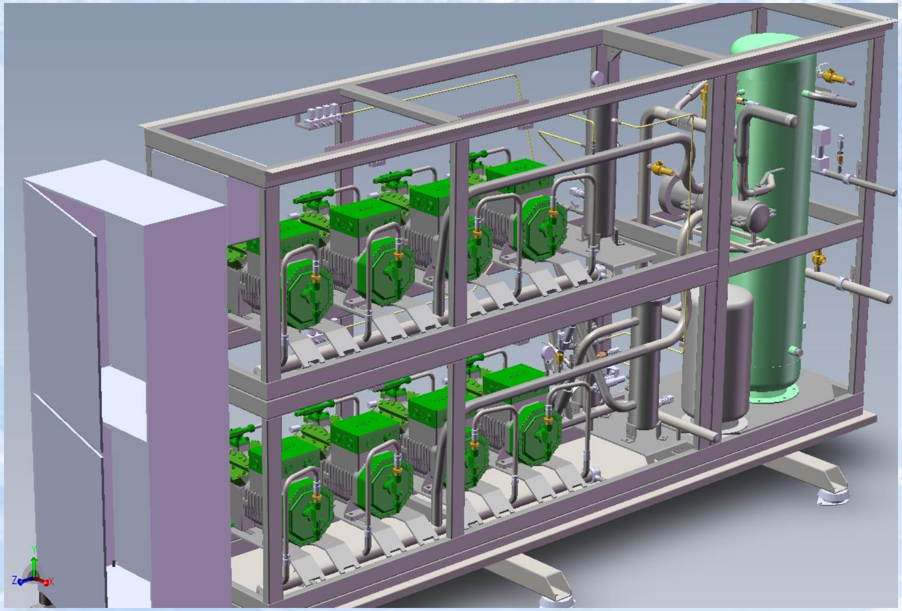
- Natural Refrigerant
- Low GWP Natural refrigerant
- No intermediate media
- Energy efficiency…

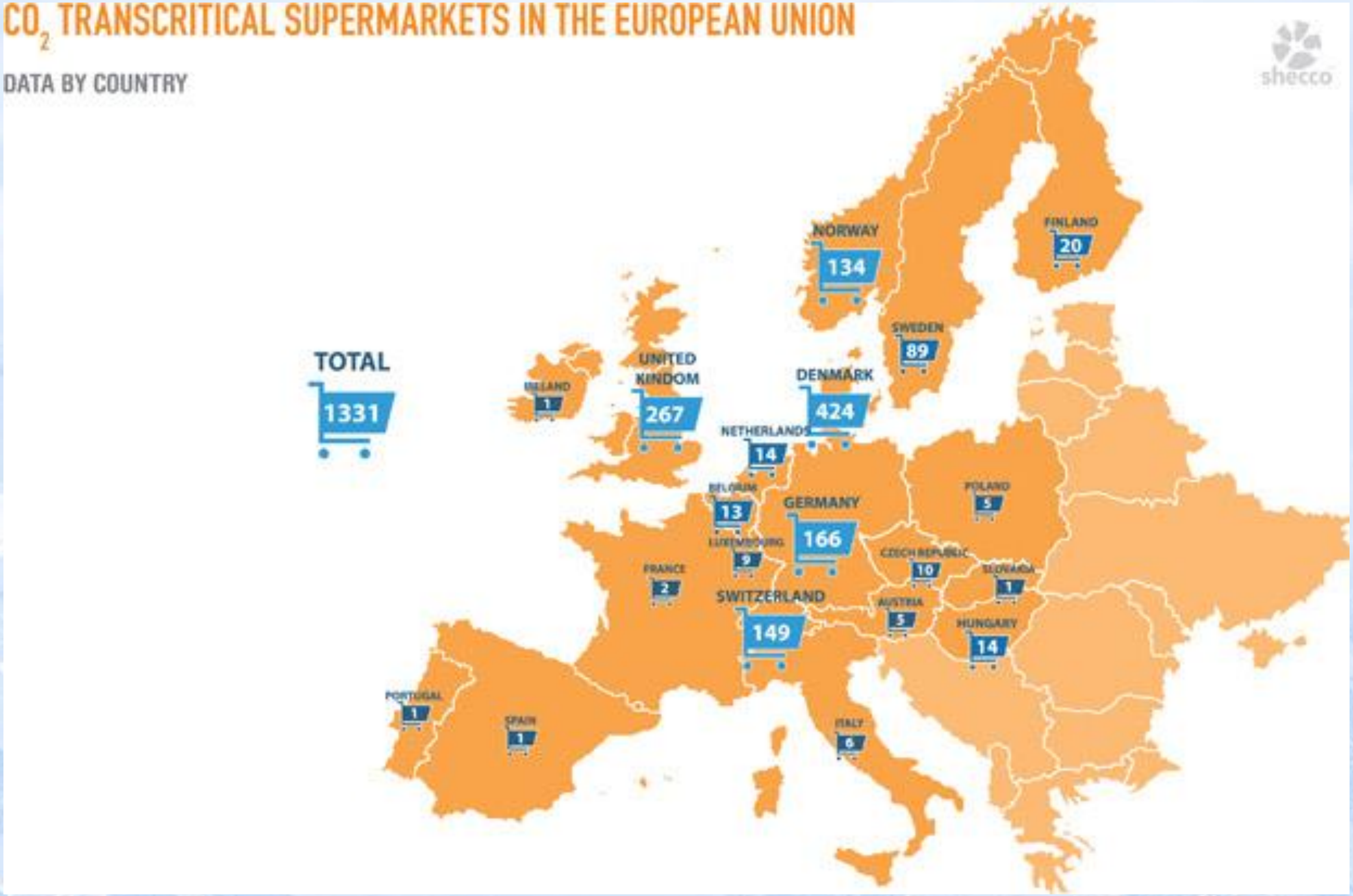
Challenges

- Requires high pressure components
- Lack of trained personnel
- Large Number of compressors for large I.R installations

What are the incentives in considering the use of transcritical CO2 refrigeration

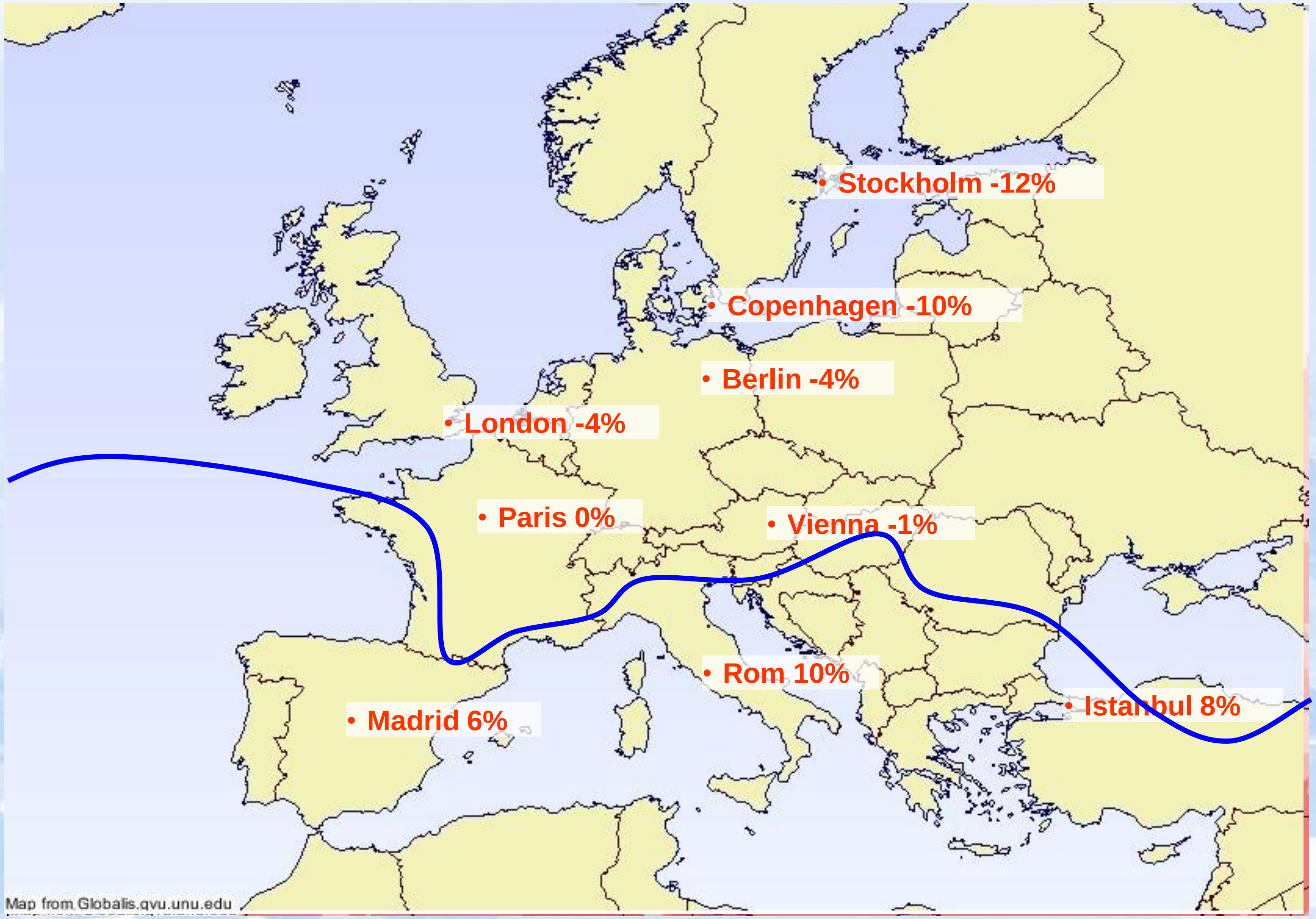
- Negligible environmental impact
- Legislation: F-gas regulations (Europe), California stricter laws. etc
- Efficiency, Energy consumption





Source: www.shecco.com

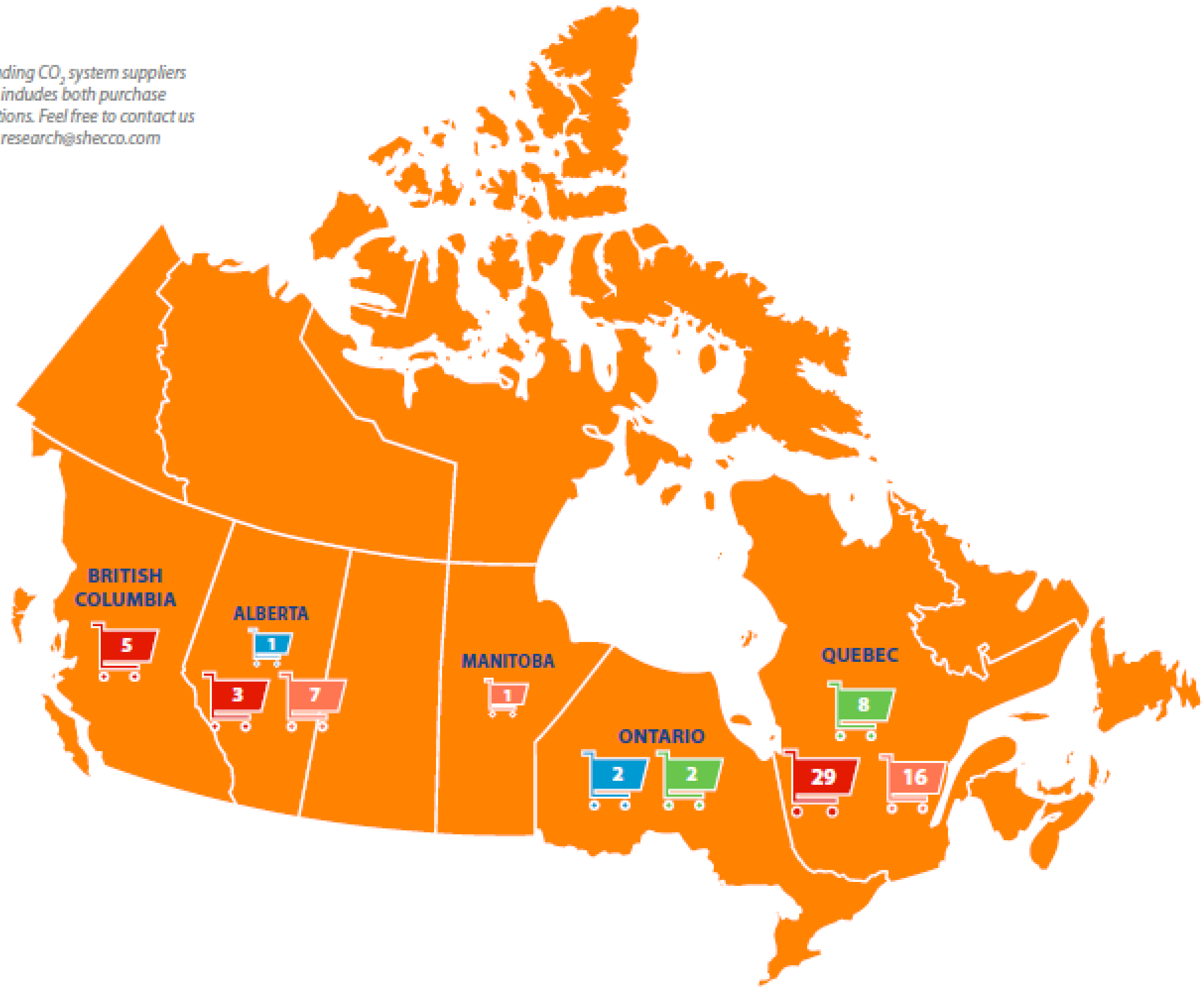
Energy Consumption of Singleo Stage Transcritical CO_2 compared to Single Stage R404A



CO_2 SUPERMARKETS IN CANADA

DATA BY PROVINCE

These figures are based on a 2012 survey of leading CO_2 system suppliers and commercial end-users. The data collected includes both purchase orders for CO_2 systems and completed installations. Feel free to contact us to add your data to the map. Send an email to research@shecco.com



2012

SECONDARY INSTALLATIONS	3
CASCADE INSTALLATIONS	10
TRANSCRITICAL INSTALLATIONS	61

2013

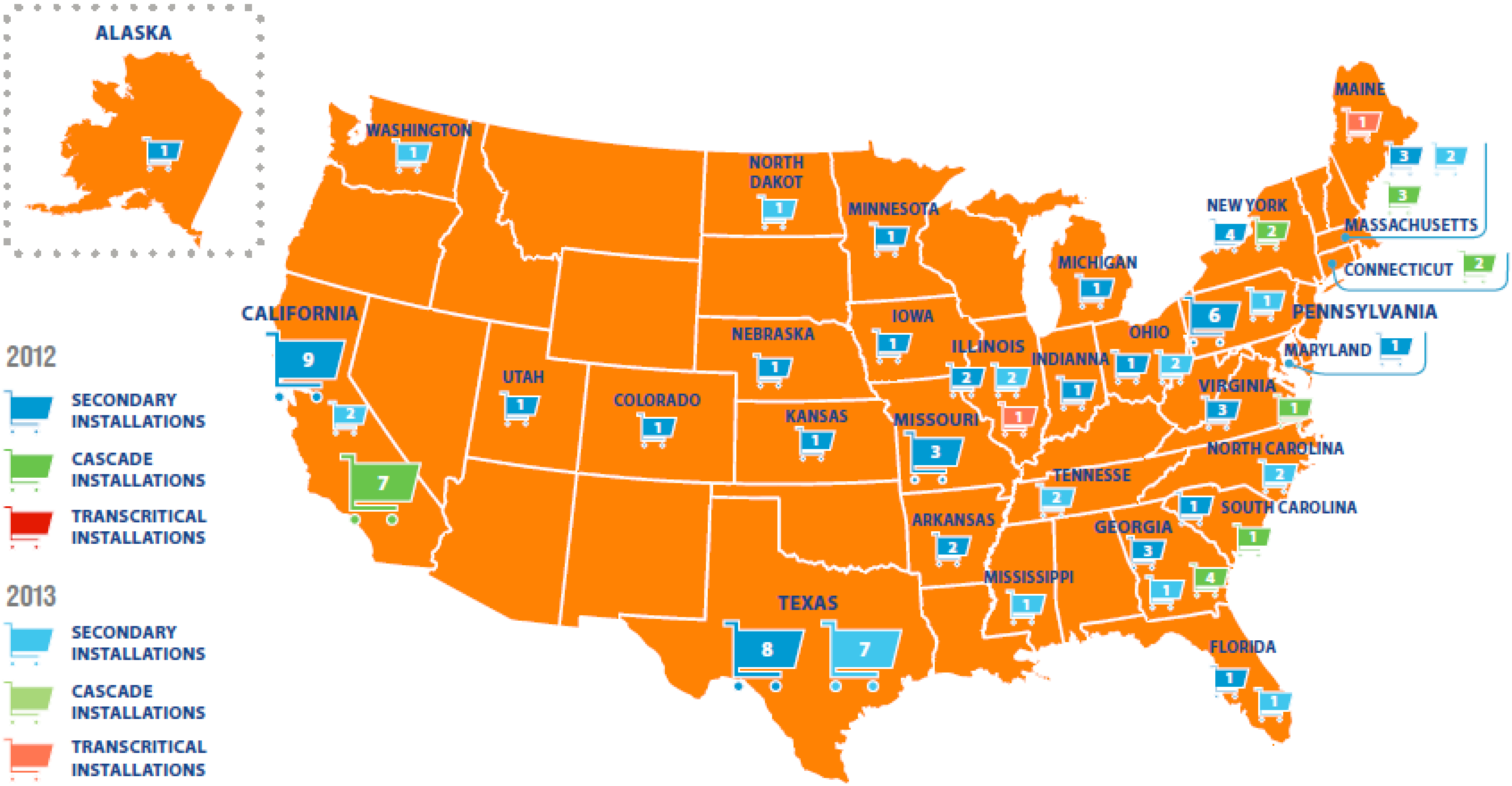
- SECONDARY INSTALLATIONS
- CASCADE INSTALLATIONS
- TRANSCRITICAL INSTALLATIONS

Source: www.shecco.com

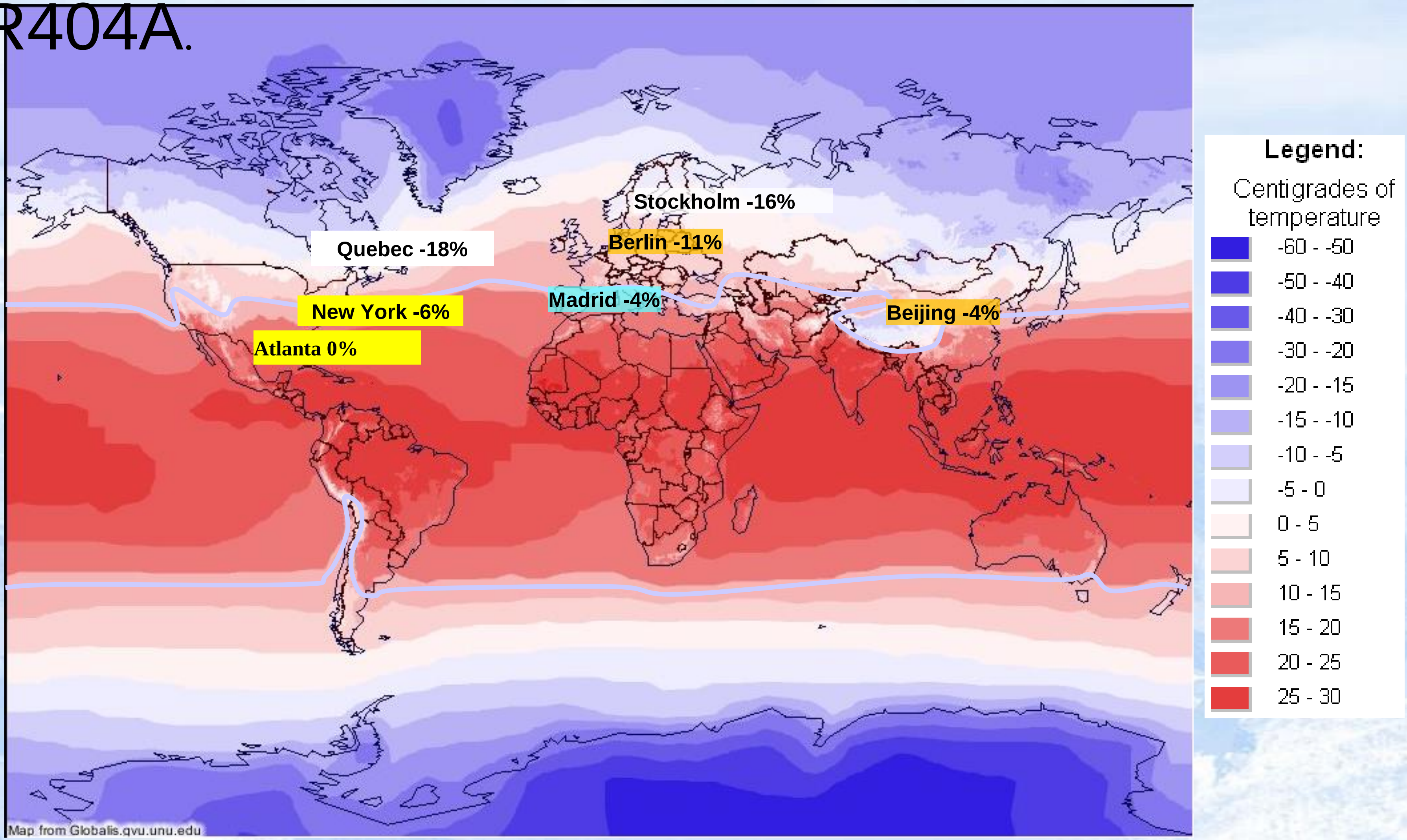
CO_2 SUPERMARKETS IN THE UNITED STATES OF AMERICA

DATA BY STATE

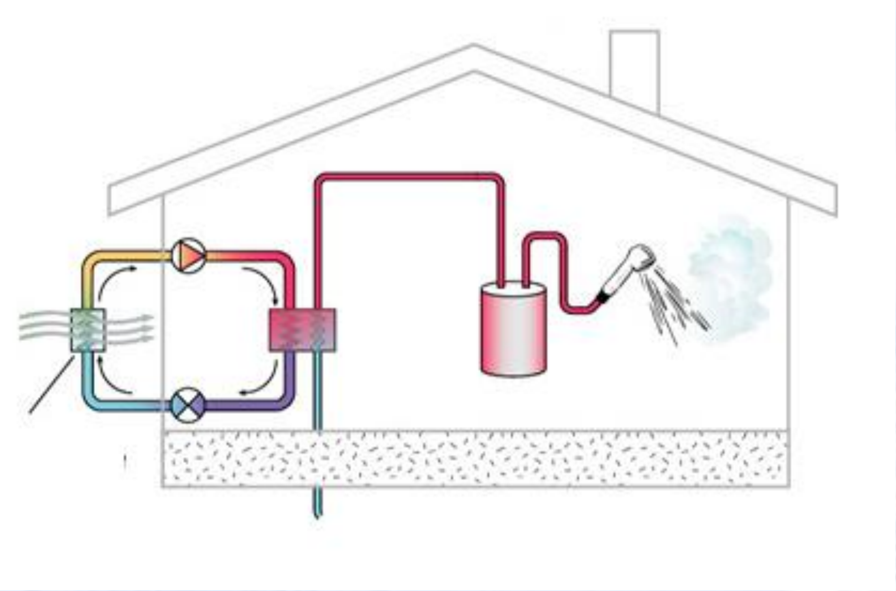
These figures are based on a 2012 survey of leading CO_2 system suppliers and commercial end-users. The data collected indudes both purchase orders for CO_2 systems and completed installations. Feel free to contact us to add your data to the map. Send an email to research@shecco.com

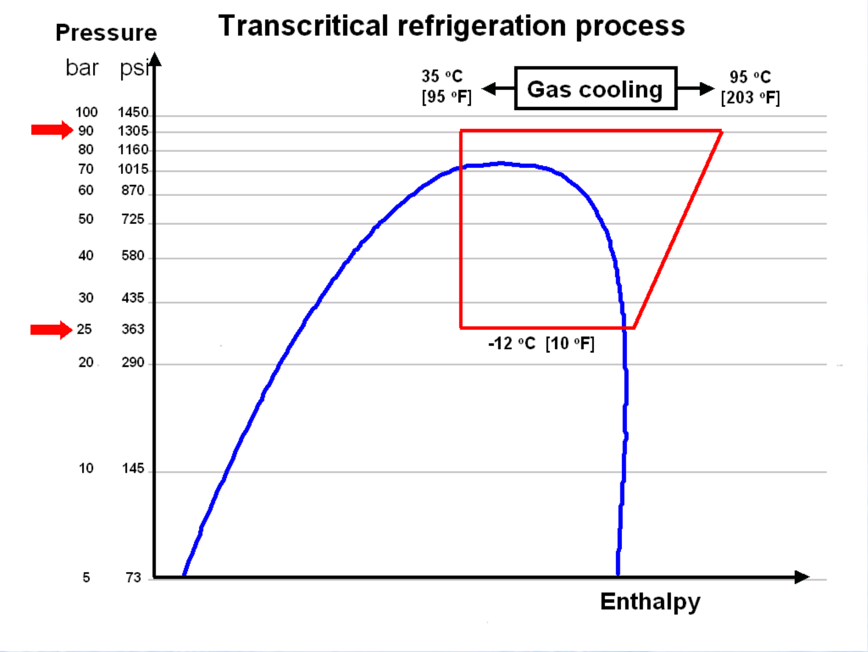


Energy Consumption of TWO Stage transcritical **BOOSTER** CO_2 compared to single Stage R404A.

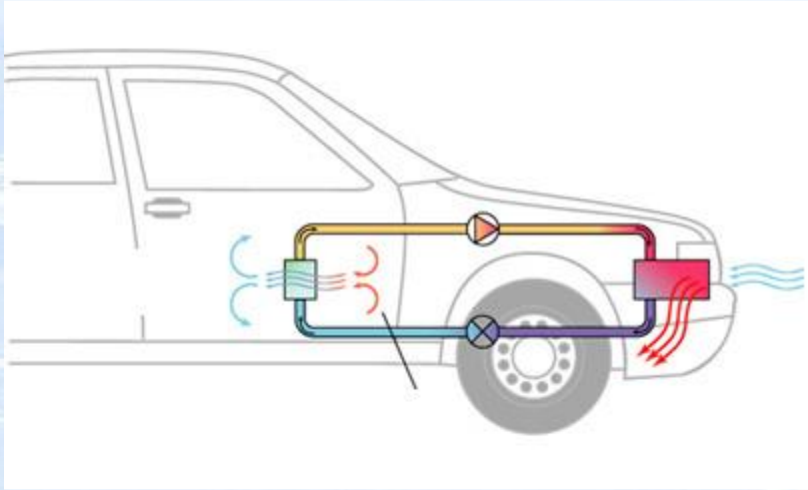


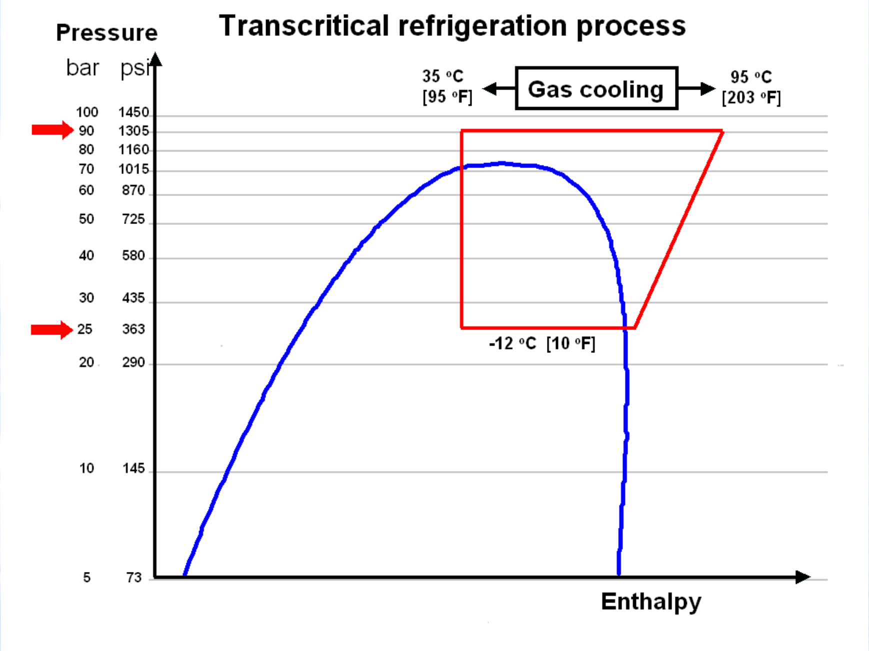
Residential CO_2 heatpump application for hot water production





CO_2 Automotive aircondition application





CO_2 Applications in Focus

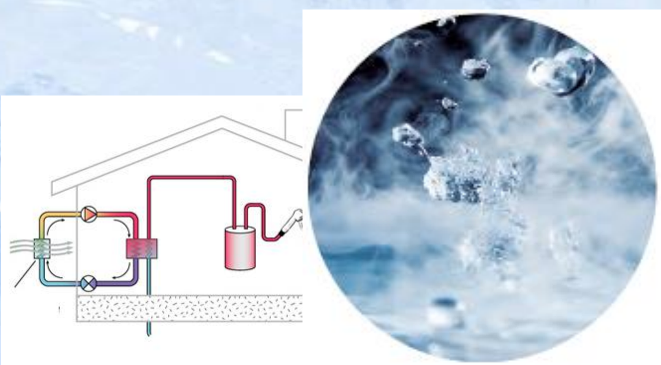
Food Retail
Subcritical

Transcritical

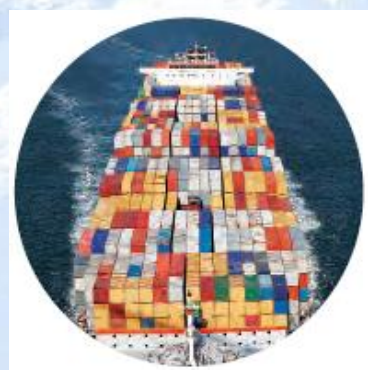
Transcritical
Booster System

Industrial Ref
Subcritical
pumped

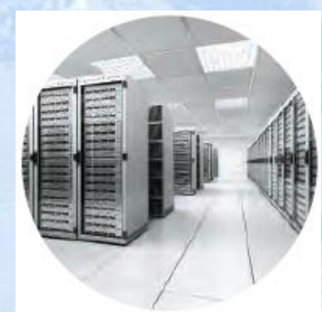
Heat Pumps
Transcritical



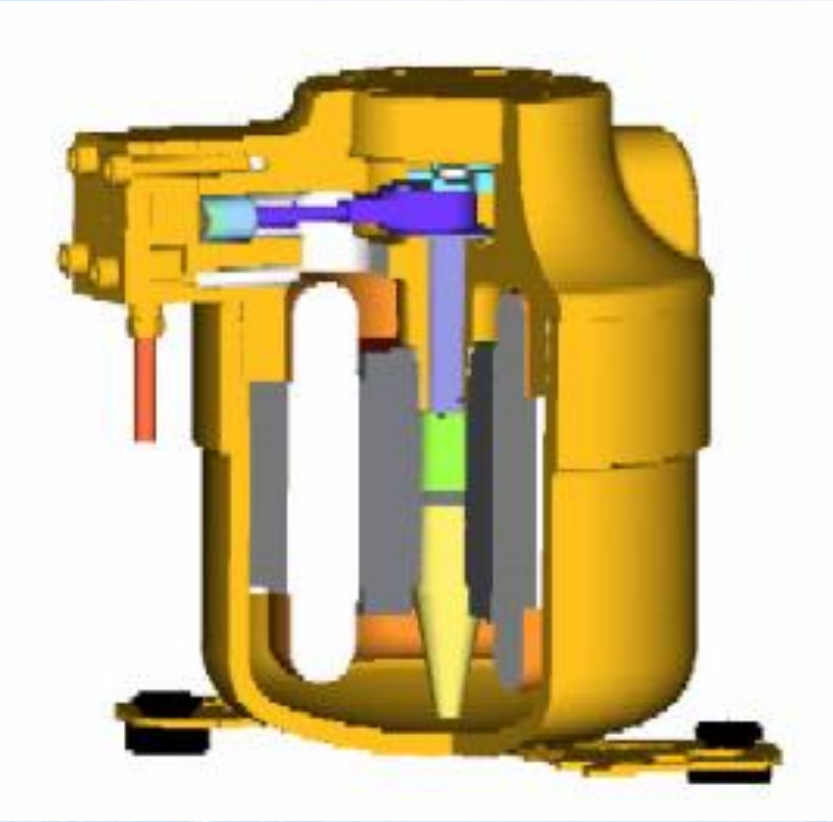
Transport Refrigeration
Transcritical

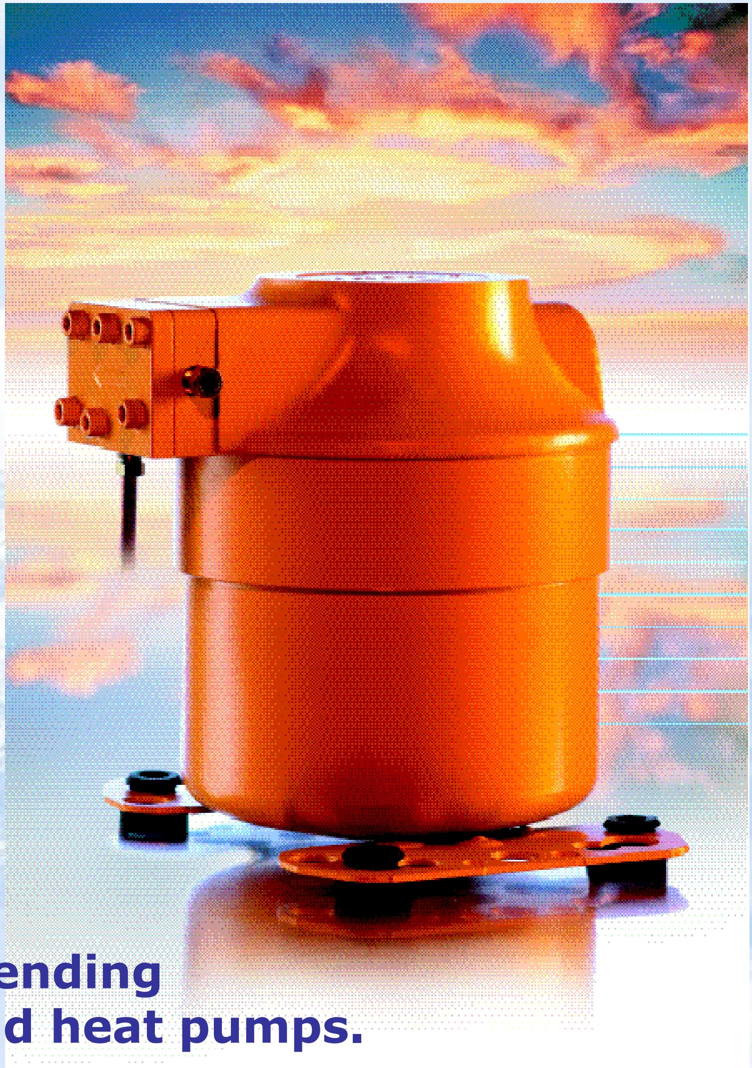


Server &
Electronics Cooling
Transcritical & Subcritical



Hermetic Transcritical CO_2 compressor

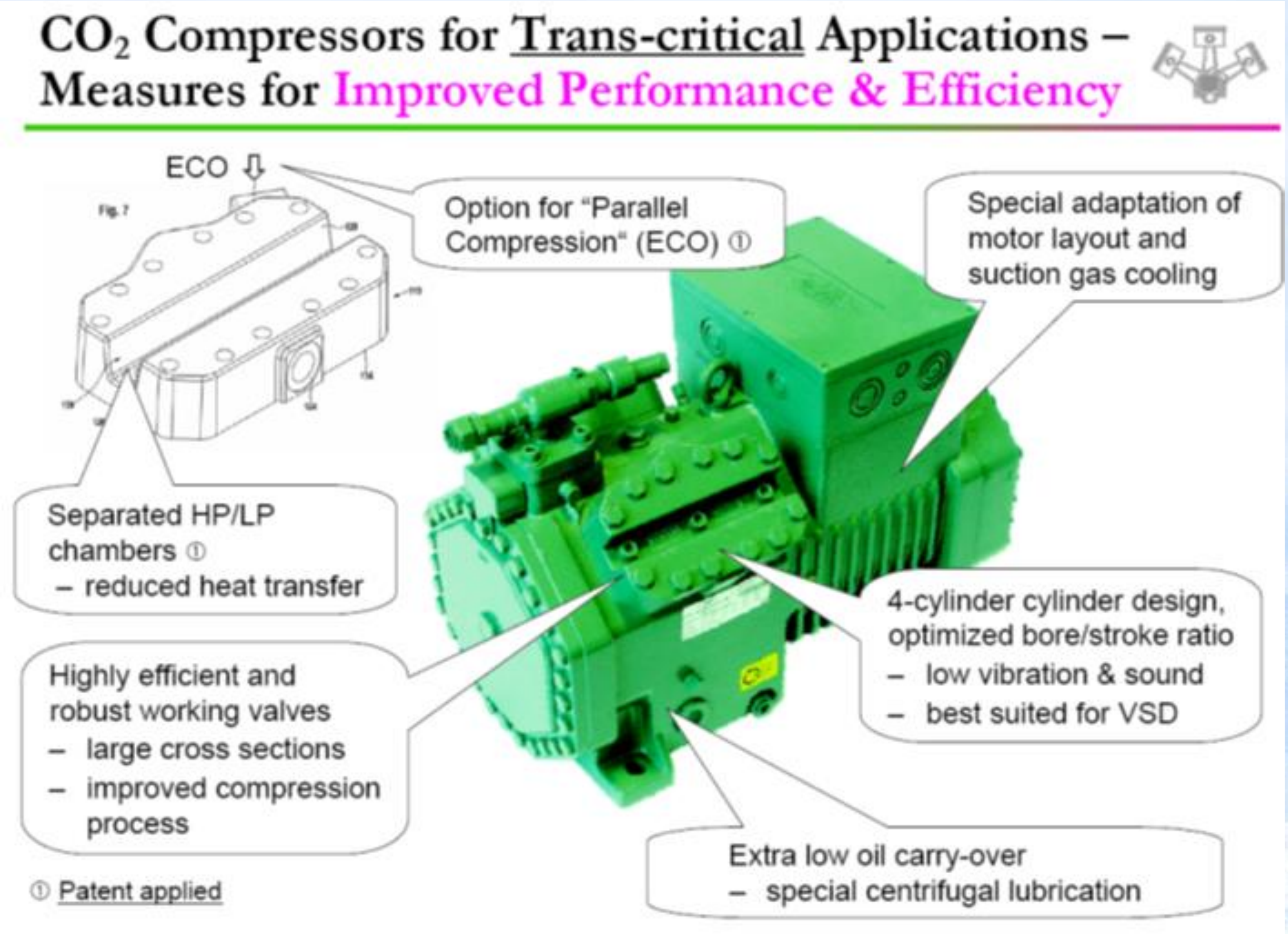




Application:

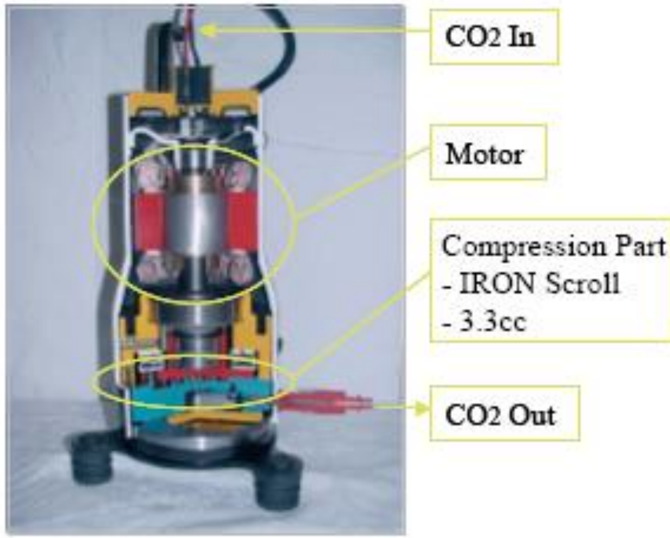
Light commercial applications like vending machines, small air-conditioners, and heat pumps.

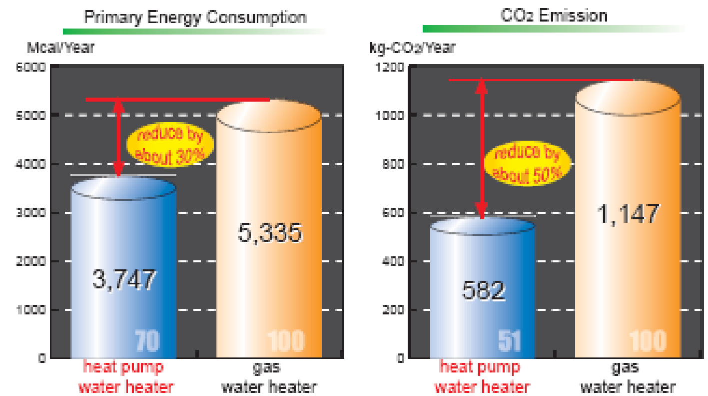
Semi-Hermetic Transcritical CO_2 compressor



CO_2 water heater

Prototype
(80 x 35 x 100cm,
Capacity: 4.5 kW)

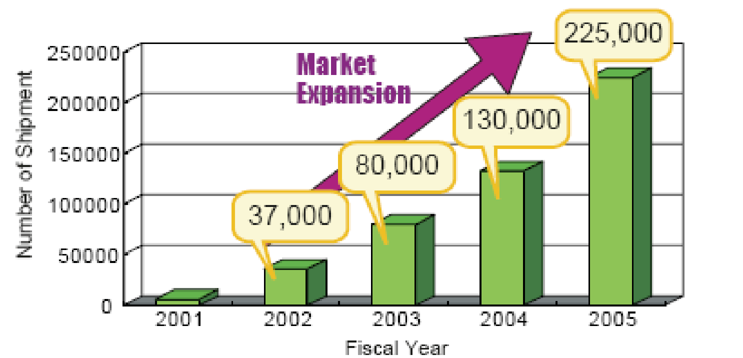




1. The equivalent hot water amount at the temperature of 43 °C on the L mode of IBEC[*1] is used for the standard water heater load.
2. The ambient air temperature and the tap water temperature are based on JRA4050:2005[*2].
3. The primary energy intensity for electricity is 2.3 Mcal/kWh(night), one for city gas is 11 Mcal/m³.

1. The equivalent hot water amount at the temperature of 43 °C on the L mode of IBEC[*1] is used for the standard water heater load.
2. The ambient air temperature and the tap water temperature are based on JRA4050:2005[*2].
3. The CO_2 emission intensity for electricity is 0.357 kg-CO2/kWh, one for city gas is 2.364 kg-CO2/m³.

Figure 9: Photographs of various ECO CUTEs.



- 5 millions installations in Japan 2010

Supermarket transcritical package

Natural Resources Canada | Ressources naturelles Canada

CASE STUDY

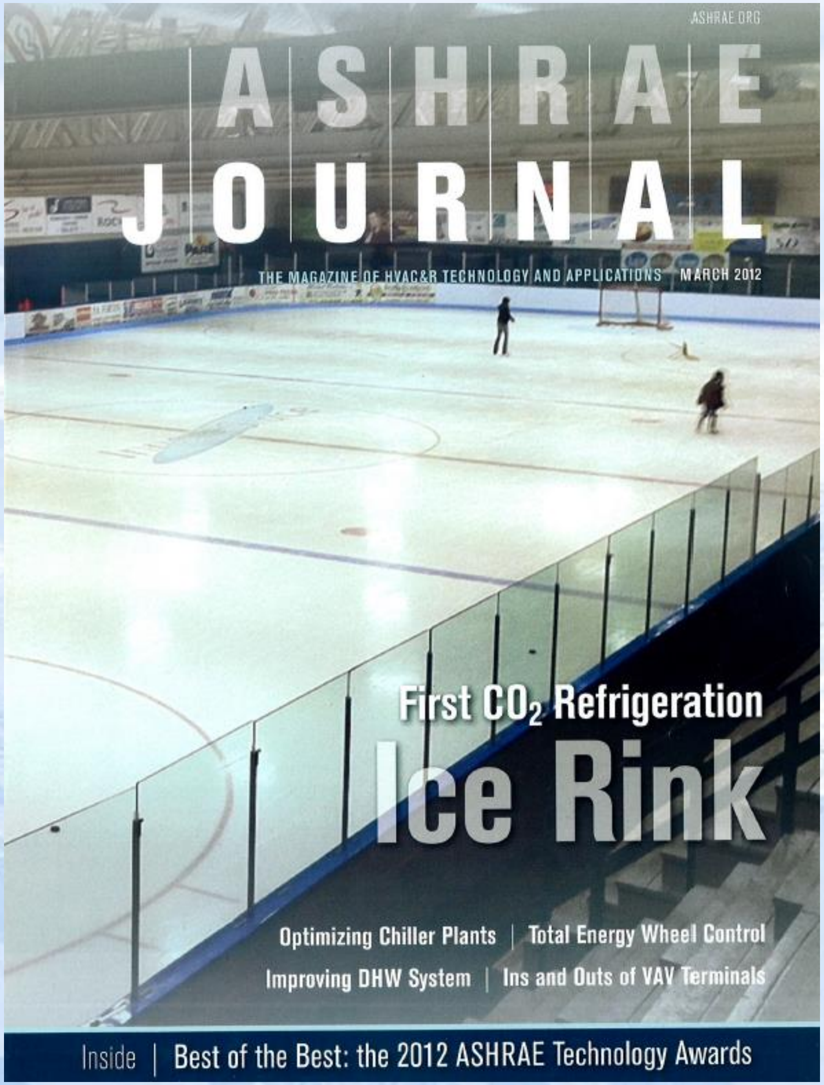
Using CO_2 for Cold Distribution at a Loblaw Supermarket

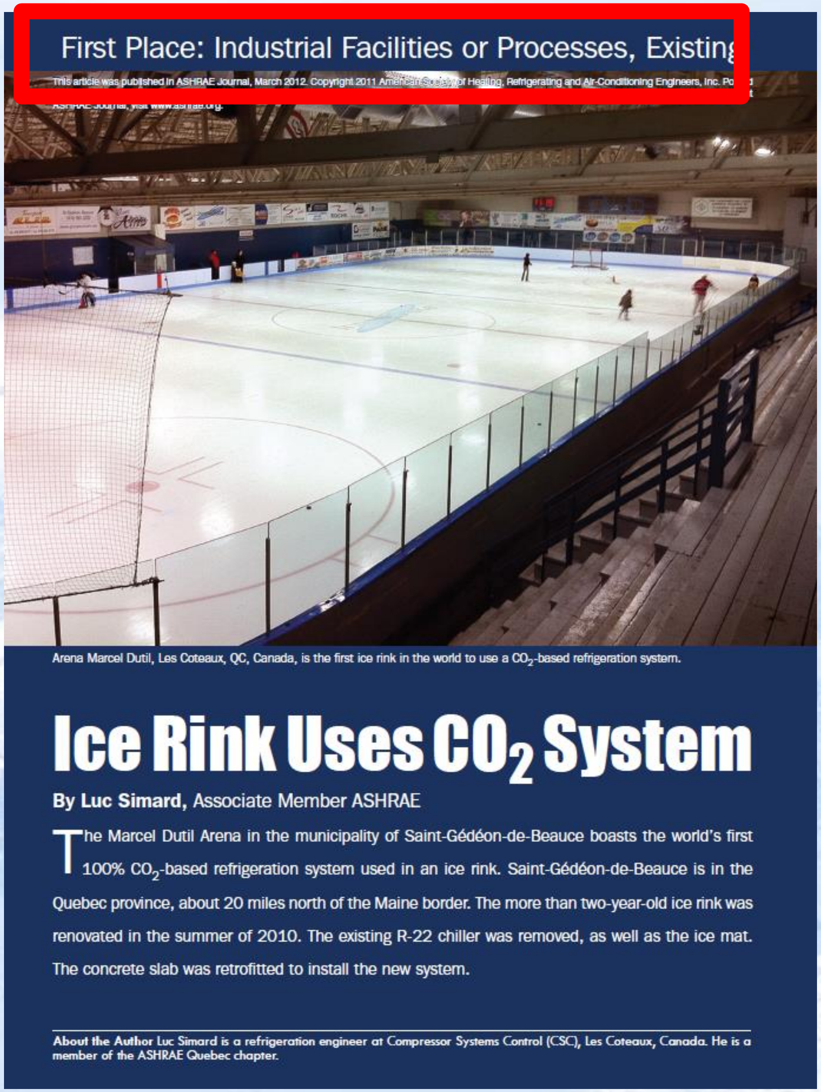
Canada

CO_2 as brine system

Ammonia/CO_2 mechanical room

Transcritical CO_2 Ice Rink Systems





First Place: Industrial Facilities or Processes, Existing

Arena Marcel Dutil, Les Coteaux, QC, Canada, is the first ice rink in the world to use a CO_2-based refrigeration system.

Ice Rink Uses CO_2 System

By **Luc Simard,** Associate Member ASHRAE

The Marcel Dutil Arena in the municipality of Saint-Gédéon-de-Beauce boasts the world's first 100% CO_2-based refrigeration system used in an ice rink. Saint-Gédéon-de-Beauce is in the Quebec province, about 20 miles north of the Maine border. The more than two-year-old ice rink was renovated in the summer of 2010. The existing R-22 chiller was removed, as well as the ice mat. The concrete slab was retrofitted to install the new system.

About the Author Luc Simard is a refrigeration engineer at Compressor Systems Control (CSC), Les Coteaux, Canada. He is a member of the ASHRAE Quebec chapter.

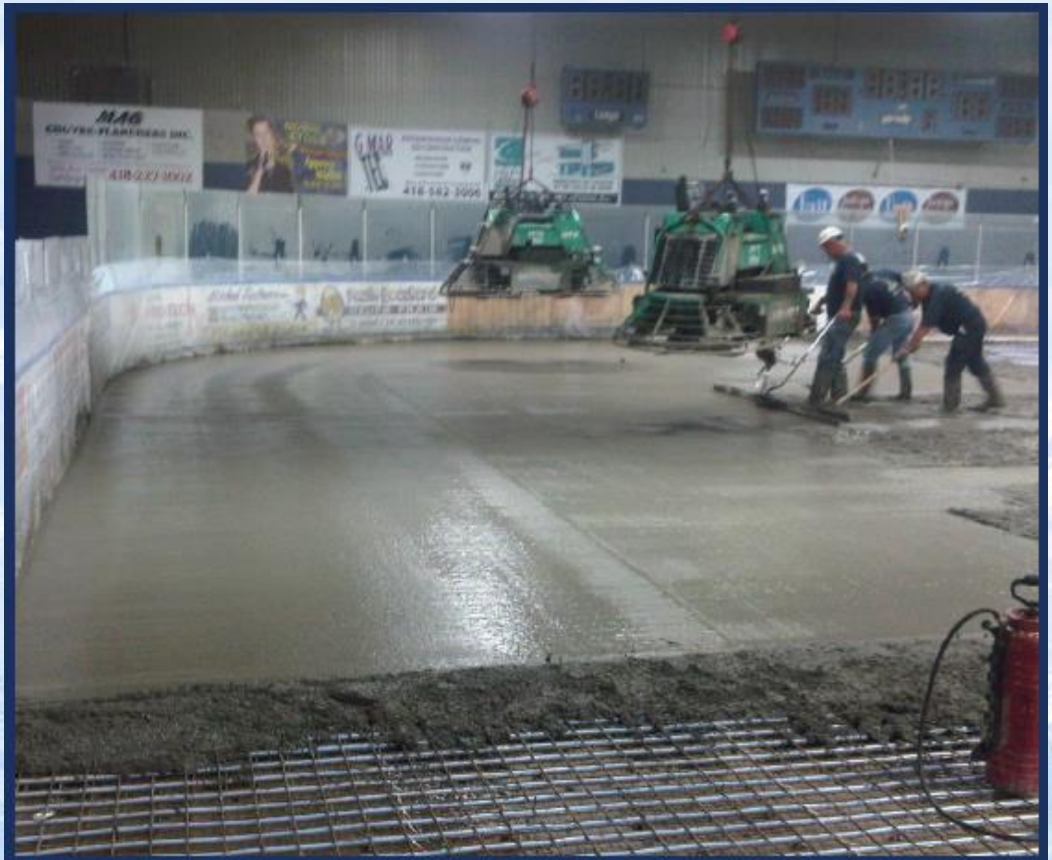
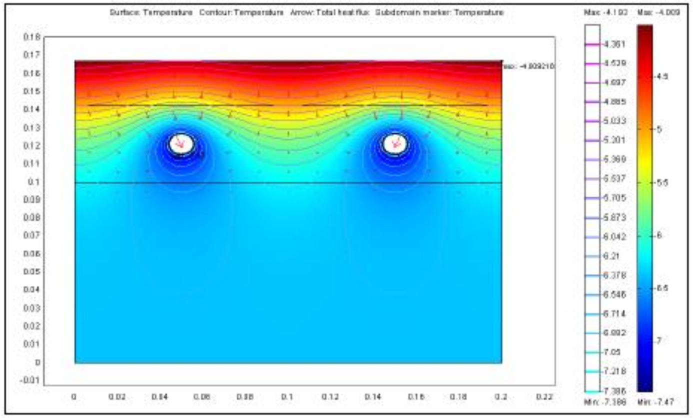


Photo 1: Concrete poured over new copper tube network.

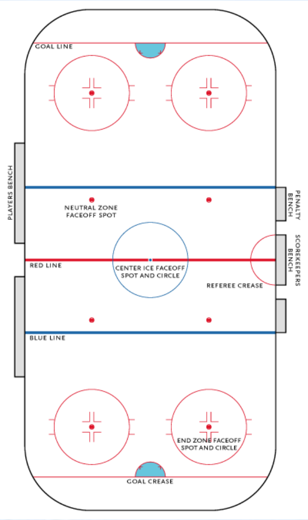


Trancritical rink package with pumped CO2 for the floor

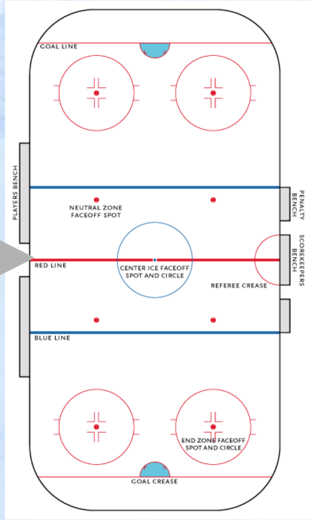
Photo 2: CO_2 ice rink chiller package.

Trancritical rink package with glycol floor

Phase 1



Phase 2



System Advantage

Elimination of inefficient pumps for circulating brine or glycol. Savings of more than 14 000 kWh / Month.

Elimination of evaporative condensers

The system provides ALL the needs of the ICE RINK FACILITIES more then 25% energy saving over HFC.

Incomparable Ice Surface quality. Quick freeze after resurfacing and no Ice temperature fluctuation on the ICE RINK latent heat.

The 100% CO_2-based refrigeration system for ice rinks that was developed in this project is a unique refrigeration system that uses the natural refrigerant R-744 (carbon dioxide) as primary and secondary working fluid (this system has Canadian patents with U.S. patents pending) (*Figure 1*). The R-744 is a natural, non-toxic, non-corrosive and highly efficient refrigerant. As opposed to the traditional solutions that use ammonia or Freon chillers, and glycol or brine as secondary fluids, this 100% CO_2-based refrigeration system does not use any secondary fluid to cool the concrete slab.

In this case, carbon dioxide is pumped from a low pressure receiver directly into a tubing network installed in the concrete slab. In addition, since there is no secondary fluid, the evaporating temperature of CO_2 can be set at 19°F (–7°C) while keeping the ice sheet at 23°F (–5°C). **The result is an evaporating temperature higher than all other standard ice rink refrigeration systems.** The tubing network is made of a specially designed plastic-coated soft copper tube.

The design recirculation ratio of liquid CO_2 in the tubing network is 1.5. Since the phase change of liquid CO_2 is not completed in the copper tubing network located in the concrete slab, no superheat is created. The tube network configuration (number of passes) does not affect ice quality because inlet and outlet temperatures of liquid CO_2 are the same. So, the temperature of the concrete slab is the same over the entire surface.

By comparison, the nominal flow rate of a 90 ton (317 kW) ice rink chiller using 100% CO_2 technology would be 30 gpm (1.9 L/s) compare to 500 to 600 gpm (32 L/s to 38 L/s) in secondary fluid applications. Pumping power is reduced up to 90% compared to traditional secondary fluid pump power.

The tube network configuration in the concrete slab is only limited by pressure drop. Fortunately, CO_2 liquid viscosity is low even at a low temperature. For this reason, the increase in pressure of the circulating pump is small, and a design ΔP of 1 to 2 bar (100 kPa to 200 kPa) is common.

The tubing network is made with ½ in. OD plastic-coated copper tubing. The tube spacing is 4 in. (102 mm) center to center. The tubes are normally installed on the longest side (200 ft [61 m] for NHL size rinks) with a return bend installed at the end (two-pass configuration).

In this configuration, each pass has a length of approximately 400 ft. (122 m). The distribution manifolds are located

Building at a Glance

Marcel Dutil Arena

Location: Saint-Gédéon-de-Beauce, QC

Owner: Municipalite St-Gédéon-de-Beauce

Principal Use: Ice Rink

Gross Square Footage: 25,000

Substantial Completion/Occupancy: 2010

2012 Technology Award Case Studies

St-Gédéon (CO_2) 2010–2011 Season				Reference NH_2/Brine 2010–2011 Season			
	kW/h	Cost ($)	Backup Cost ($)		kW/h	Cost ($)	Backup Cost ($)
Sept. 10	61,560	6,103.15	–	Sept. 10	93,780	8,101.00	48.08
Oct. 10	83,160	7,040.23	–	Oct. 10	97,020	8,157.86	1,063.11
Nov. 10	89,280	7,197.65	1,399.95	Nov. 10	10,3140	8,742.18	367.30
Dec. 10	82,080	6,661.33	1,965.90	Dec. 10	130,320	10,947.84	1,144.69
Jan. 11	84,240	6,874.00	2,026.46	Jan. 11	115,560	8,667.94	1,850.10
Feb. 11	61,920	5,997.25	1,745.96	Feb. 11	113,220	9,918.45	374.43
Mar. 11	96,480	7,658.28	1,550.77	Mar. 11	93,960	8,380.71	1,956.06
Apr. 11	52,560	5,909.00	–	Apr. 11	39,600	4,669.27	1,844.48
	611,280	**53,440.89**	**8,689.04**		**786,600**	**67,615.25**	**8,648.25**

Table 1: Comparative energy cost for the first year of operation.

Because the concrete slab already existed, we poured 2 in. (51 mm) of new concrete over it to install the new copper tube network (*Photo 1*, Page 40).

The new refrigeration package was built in the factory and delivered on site (*Photo 2*, Page 40).

The main feature of this project is the energy consumption reduction when compared to similar projects using standard ice rink chiller/secondary fluid technologies. Because the system uses a part of the total heat reclaim, it covers all hot water needs for the facility at no additional cost. The hot water storage tank delivers 167°F (75°C) water at a constant temperature to the building. During the last season, the facility never ran out of hot water, and it never used back-up heating.

The 100% CO_2 refrigeration system for the ice rink is also connected to a warm glycol loop through another heat reclaim heat exchanger to recover the rest of the energy output. The

Heat reclaim for the building

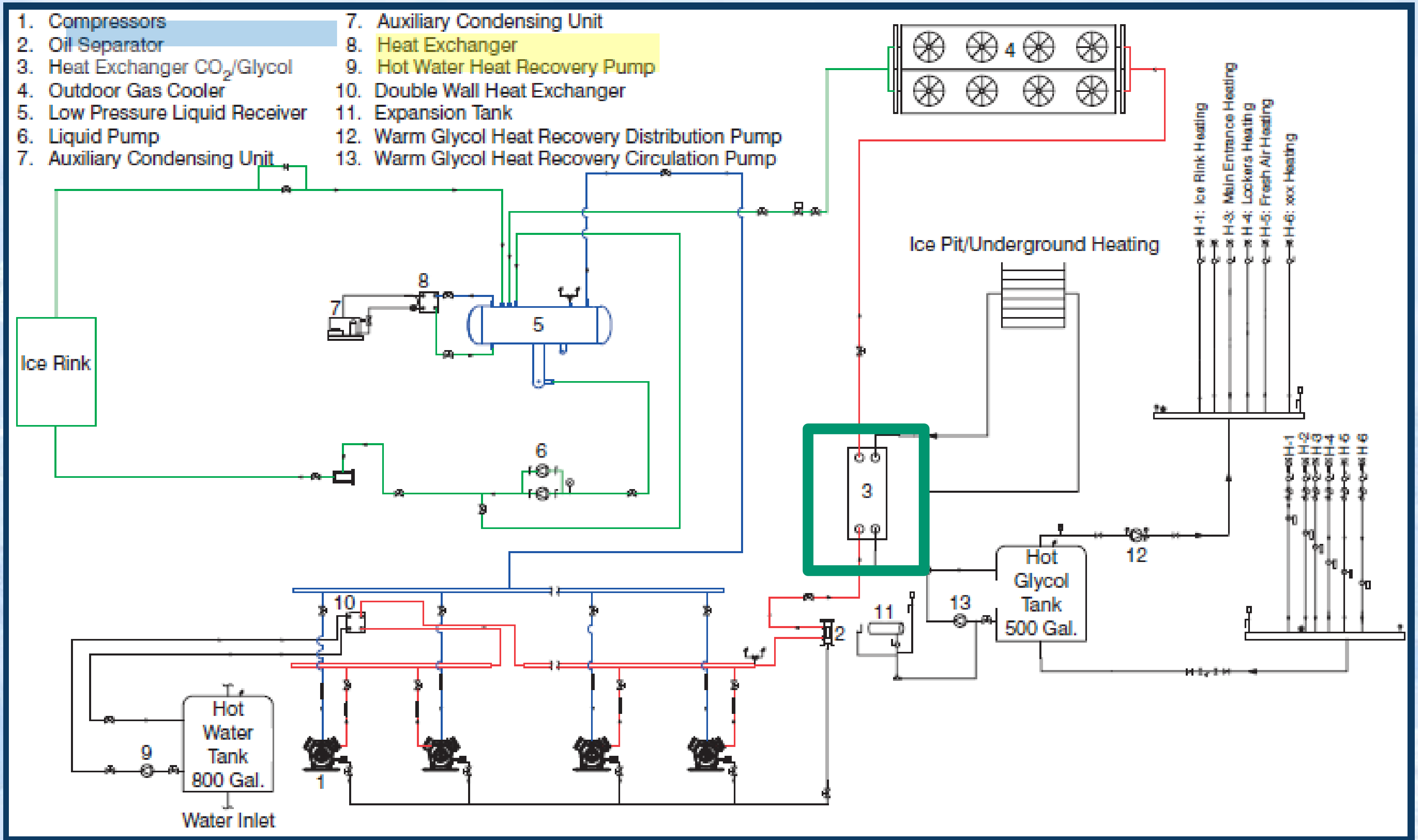
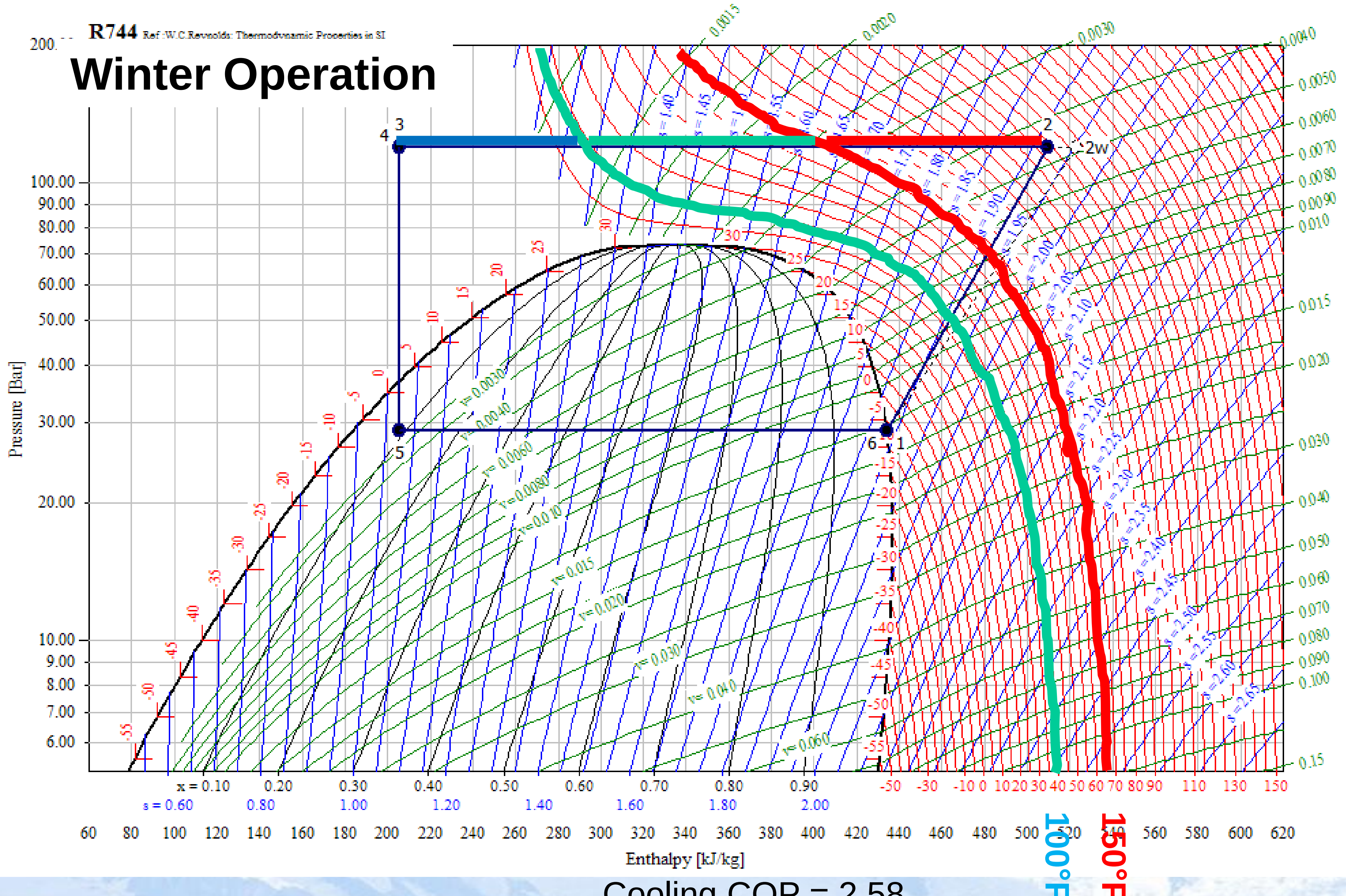


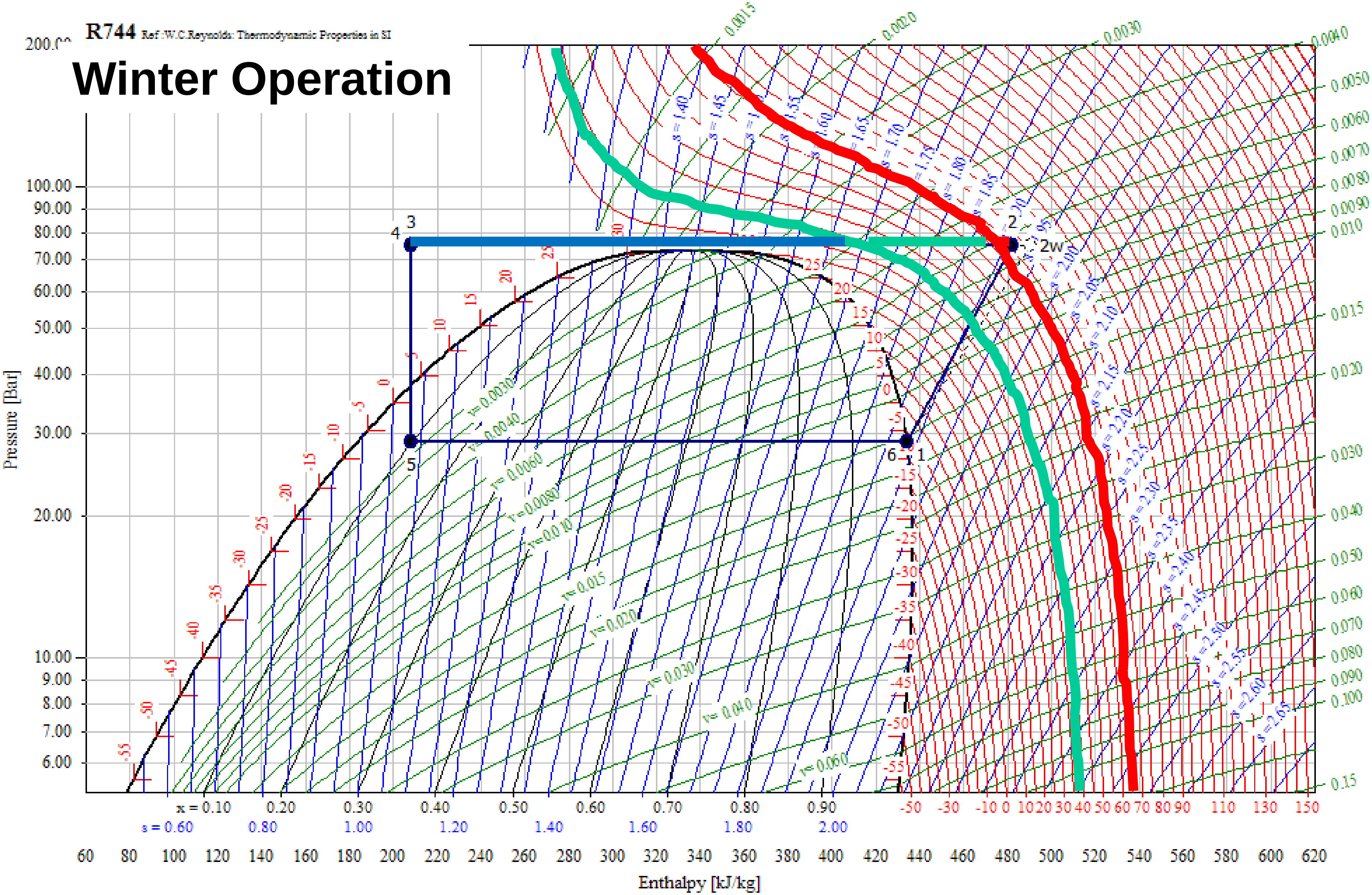
Figure 1: Schematic of CO_2 refrigeration system that does not use any secondary fluid to cool the concrete slab.

Winter Operation



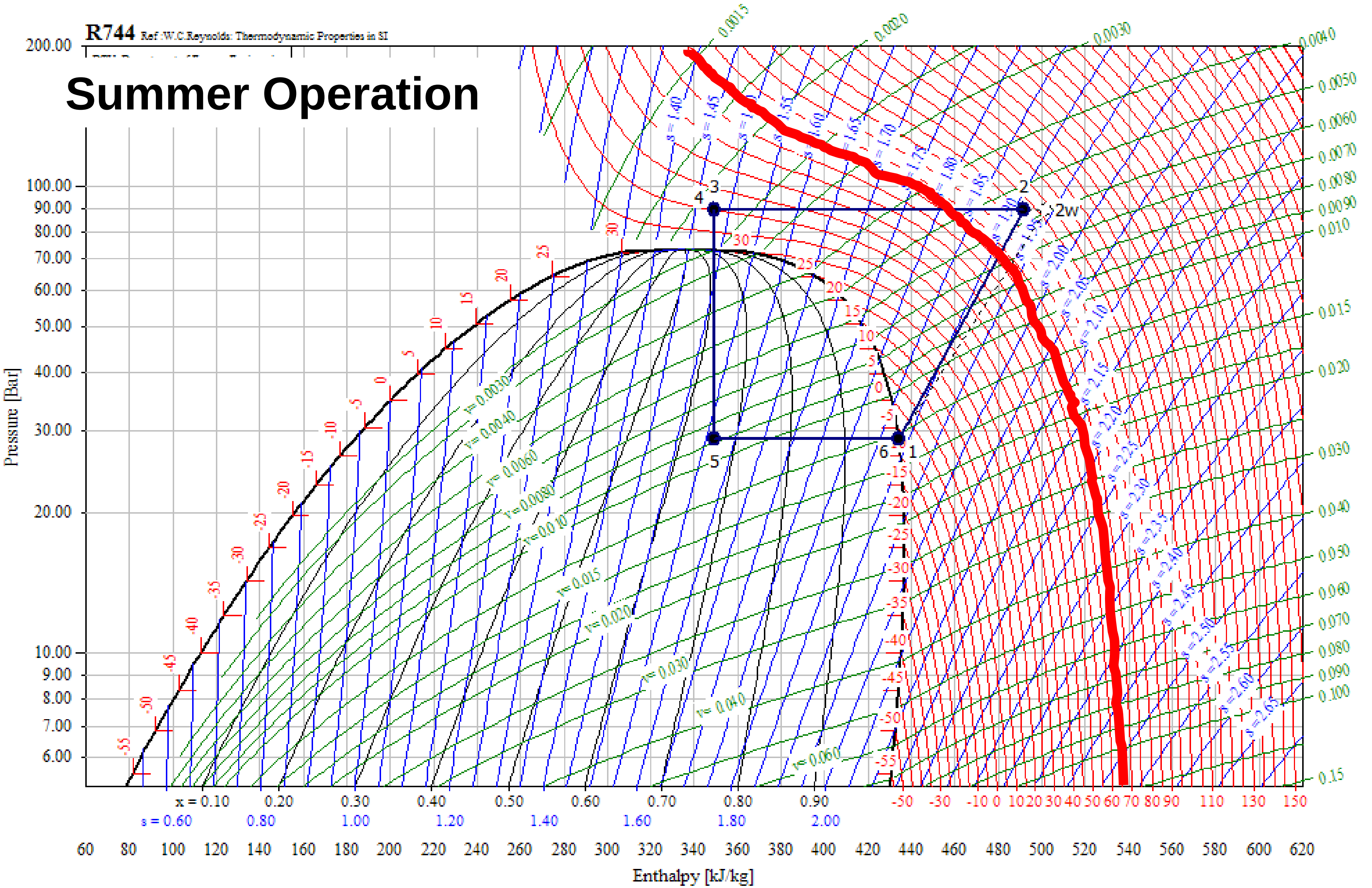
Cooling COP = 2.58
{100 TR → 183 HP}

Winter Operation



Cooling COP = 4.03
{100 TR → 117 HP}

Summer Operation



Cooling COP = 1.26
{100 TR → 375 HP}

Energy Efficiency

Montreal Area Weather Data				SST=-8Cel		R744			
Bin Temp. (deg. F)	Bin Hours (# hrs)	T ext (C)	T out GC (C)	GC Pressure (BAR)	COP Dorin	COP annuel Dorin		COP FLOATING	
92	6	33.33	35.33	89	1.83	0.0013	100%	0.0013	0%
87	29	30.56	32.56	82	2.04	0.0068	100%	0.0068	0%
82	154	27.78	29.78	76	2.33	0.0409	100%	0.0409	0%
77	360	25	27	70	2.7	0.1109	100%	0.1109	0%
72	609	22.22	24.22	64	3.17	0.2203	100%	0.2203	0%
67	558	19.44	21.44	60	3.65	0.2324	100%	0.2324	0%
62	776	16.67	18.67	56	4.25	0.3764	75%	0.3491	25%
57	718	13.89	15.89	55	4.6	0.3769	75%	0.3470	25%
52	671	11.11	13.11	55	4.8	0.3675	75%	0.3379	25%
47	629	8.33	10.33	55	5	0.3589	75%	0.3296	25%
42	477	5.56	7.56	55	5.15	0.2803	75%	0.2575	25%
37	753	2.78	4.78	55	5.3	0.4554	50%	0.3807	50%
32	714	0	5	55	5.3	0.4318	50%	0.3610	50%
27	539	-2.78	5	55	5.3	0.3260	50%	0.2725	50%
22	334	-5.56	5	55	5.3	0.2020	25%	0.1523	75%
17	394	-8.33	5	55	5.3	0.2383	25%	0.1796	75%
12	333	-11.11	5	55	5.3	0.2014	25%	0.1518	75%
7	274	-13.89	5	55	5.3	0.1657	0%	0.1113	100%
2	205	-16.67	5	55	5.3	0.1240	0%	0.0833	100%
-3	95	-19.44	5	55	5.3	0.0575	0%	0.0386	100%
-8	86	-22.22	5	55	5.3	0.0520	0%	0.0349	100%
-13	27	-25	5	55	5.3	0.0163	0%	0.0110	100%
-18	18	-27.78	5	55	5.3	0.0109	0%	0.0073	100%
-23	3	-30.56	5	55	5.3	0.0018	0%	0.0012	100%
-28	1	-33.33	5	55	5.3	0.0006	0%	0.0004	100%
TotalHours	**8763**			COP refrigeration		**4.66**		**4.0**	

Montreal Area Weather Data				SST=-8Cel		R744
Bin Temp. (deg. F)	Bin Hours (# hrs)	T ext (C)	T out GC (C)	GC Pressure (BAR)	COP	COP annuel
92	6	33.33	35.33	89	1.83	0.0013
87	29	30.56	32.56	82	2.04	0.0068
82	154	27.78	29.78	76	2.33	0.0409
77	360	25	27	70	2.7	0.1109
72	609	22.22	24.22	64	3.17	0.2203
67	558	19.44	21.44	60	3.65	0.2324
62	776	16.67	18.67	75	3.02	0.2674
57	718	13.89	15.89	75	3.14	0.2573
52	671	11.11	13.11	75	3.25	0.2489
47	629	8.33	10.33	75	3.37	0.2419
42	477	5.56	7.56	75	3.47	0.1889
37	753	2.78	4.78	75	3.56	0.3059
32	714	0	5	75	3.56	0.2901
27	539	-2.78	5	75	3.56	0.2190
22	334	-5.56	5	75	3.56	0.1357
17	394	-8.33	5	75	3.56	0.1601
12	333	-11.11	5	75	3.56	0.1353
7	274	-13.89	5	75	3.56	0.1113
2	205	-16.67	5	75	3.56	0.0833
-3	95	-19.44	5	75	3.56	0.0386
-8	86	-22.22	5	75	3.56	0.0349
-13	27	-25	5	75	3.56	0.0110
-18	18	-27.78	5	75	3.56	0.0073
-23	3	-30.56	5	75	3.56	0.0012
-28	1	-33.33	5	75	3.56	0.0004
TotalHours	**8763**			COP refrigeration		**3.35**

Rink energy efficiency

Indirect cooling

Montreal Area Weather Data				SST=-12.2Cel		R744
Bin temp (deg. F)	Bin Hour (# hrs)	t ext (C)	t out GC (C)	GC Pressure (BAR)	COP	COP annuel
92	6	33.33	35.33	89	1.59	0.0011
87	29	30.56	32.56	82	1.8	0.0060
82	154	27.78	29.78	76	2.05	0.0360
77	360	25	27	68	2.38	0.0978
72	609	22.22	24.22	64	2.74	0.1904
67	558	19.44	21.44	60	3.14	0.1999
62	776	16.67	18.67	75	2.68	0.2373
57	718	13.89	15.89	75	2.79	0.2286
52	671	11.11	13.11	75	2.89	0.2213
47	629	8.33	10.33	75	3.00	0.2153
42	477	5.56	7.56	75	3.1	0.1687
37	753	2.78	4.78	75	3.20	0.2750
32	714	0	5	75	3.2	0.2607
27	539	-2.78	5	75	3.2	0.1968
22	334	-5.56	5	75	3.2	0.1220
17	394	-8.33	5	75	3.2	0.1439
12	333	-11.11	5	75	3.2	0.1216
7	274	-13.89	5	75	3.2	0.1001
2	205	-16.67	5	75	3.2	0.0749
-3	95	-19.44	5	75	3.2	0.0347
-8	86	-22.22	5	75	3.2	0.0314
-13	27	-25	5	75	3.2	0.0099
-18	18	-27.78	5	75	3.2	0.0066
-23	3	-30.56	5	75	3.2	0.0011
-28	1	-33.33	5	75	3.2	0.0004
TotalHours	8763			COP refrigeration		**2.98**

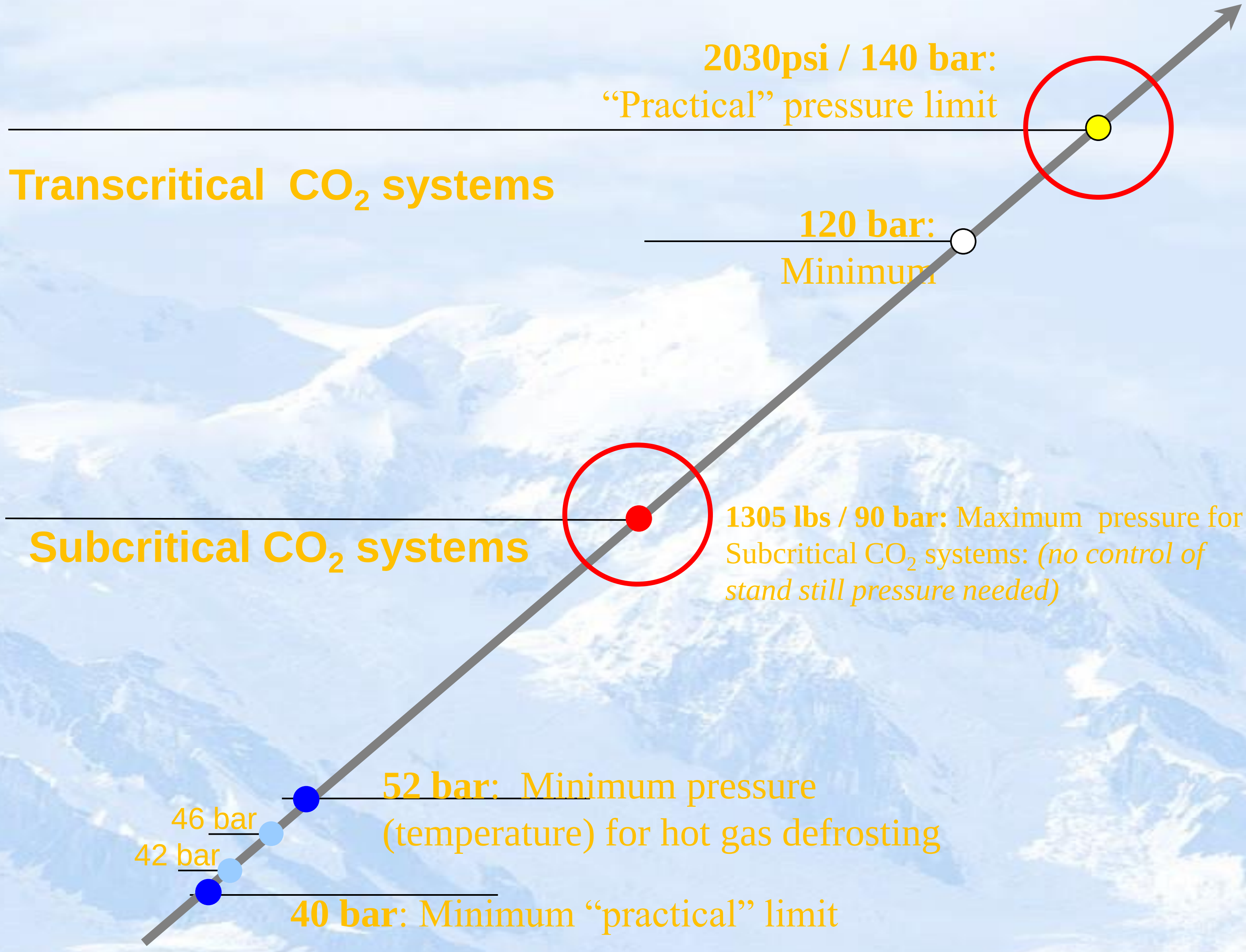
Other aspect of CO_2 systems

- Pressure during operation
- Pressure during ”stand still”
- Defrosting methods
- Pressure tolerances for safety valves (10 – 15 %)
- Codes and regulations B-52, B-31
- Contamination with water

Pressure rating of CO_2 systems

- Typical working pressure between 15 and 35 bar, Low temp cascade
- MWP 40-50 bar, depending on defrost (Cascade and Brine)
- Stand still pressure could rise up to 85 bar (or even higher) if not taken care of – mitigation is required
- Stand still unit is a simple and cost effective method to address the issue
- Please be careful when using copper piping. MWP of copper pipes could vary a lot depending on the wall thickness

Design Pressure in CO_2 Systems



B-52 code

Table 4 (Concluded)

Refrigerant number		Minimum design pressure (gauge*)					
		Low side		High side			
				Water- or evaporator-cooled		Air-cooled	
		kPa	psig	kPa	psig	kPa	psig
R-407D	R-32/125/134a (15/15/70)	958	139	1415	205	1874	272
R-407E	R-32/125/134a (25/15/60)	1101	160	1612	234	2123	308
R-408A	R-125/143a/22 (7/46/47)	1125	163	1633	237	2139	310
R-409A	R-22/124/142b (60/25/15)	749	109	1110	161	1281	186
R-409B	R-22/124/142b (65/25/10)	798	116	1179	171	1560	226
R-410A	R-32/125 (50/50)	1626	236	2343	340	3064	444
R-411A	R-1270/22/152a (1.5/87.5/11)	922	134	1357	197	1792	260
R-411B	R-1270/22/152a (3/94/3)	974	141	1428	207	1881	273
R-411C	R-1270/22/152a (3/95.5/1.5)	989	144	1449	210	1908	277
R-412A	R-22/218/142b (70/5/25)	864	125	1257	182	1647	239
R-413A	R-218/134a/600a (9/88/3)	731	106	1095	159	1463	212
R-414A	R-22/124/600a/142b (51/28.5/4/16.5)	723	105	1070	155	1415	205
R-414B	R-22/124/600a/142b (50/39/1.5/9.5)	716	104	1065	155	1412	205
R-415A	R-23/22/152a (5/80/15)	1026	149	1480	215	1929	280
R-500	R-12/152a (73.8/26.2)	705	102	1050	152	1395	202
R-502	R-22/115 (48.8/51.2)	1112	161	1594	231	2077	301
R-503	R-23/13 (40.1/59.9)	4253	617	4253	617	4253	617
R-507A	R-125/143a (50/50)	1243	180	1803	262	2373	344
R-508A	R-23/116 (39/61)	3959	574	3959	574	3959	574
R-508B	R-23/116 (46/54)	3821	554	3821	554	3821	554
R-509A	R-22/218 (44/56)	1190	173	1708	248	2218	322
R-717	Ammonia	951	138	1473	214	2016	292
R-744	Carbon dioxide	7275	1055	7275	1055	7275	1055
R-1150	Ethylene	4938	716	4938	716	4938	716

B-52 code

5.5 Design pressures

Δ **5.5.1**

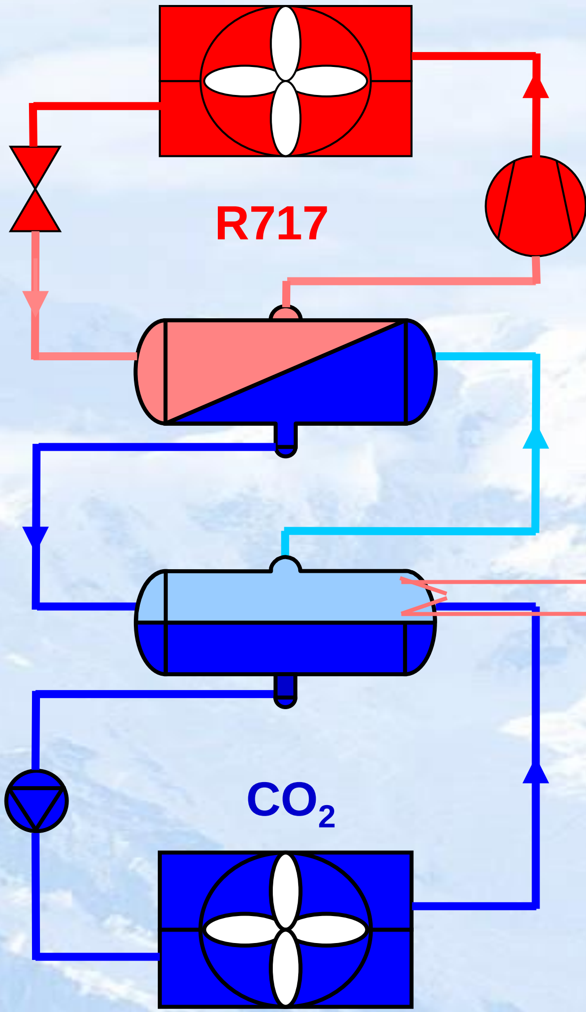
One of the following methods shall be used to determine the design pressure of the different parts of the refrigeration system:

(a) **Method 1** — The minimum design pressure shall be not less than 103 kPa (15 psig) and, except as specified in Clauses 5.5.5 to 5.5.7, shall be not less than the saturation pressure corresponding to the following temperatures:
  - (i) low sides of all systems: 27 °C (80°F); and
  - (ii) high sides of
    - (1) water- or evaporator-cooled systems: 40 °C (105°F); or
    - (2) air-cooled systems: 52 °C (125°F).

The corresponding pressures for refrigerants in common use are specified in Table 4.

(b) **Method 2** — For carbon dioxide refrigerant, when used in the low-temperature side of a double direct (cascade) system, volatile direct system, or transcritical system, the design pressure shall be 20% higher than the saturation pressure at its warmest location in the circuit under maximum operating conditions (e.g., startup or defrost conditions). The designer shall make provision for normal and emergency standstill conditions:
  - (i) through provision of a fade-out vessel;
  - (ii) by means of safe, controlled venting, utilizing a pressure-regulating relief valve, of the secondary charge; or
  - (iii) by other means, such as relieving pressure safely to a lower pressure part of the system or auxiliary-powered condensing unit.

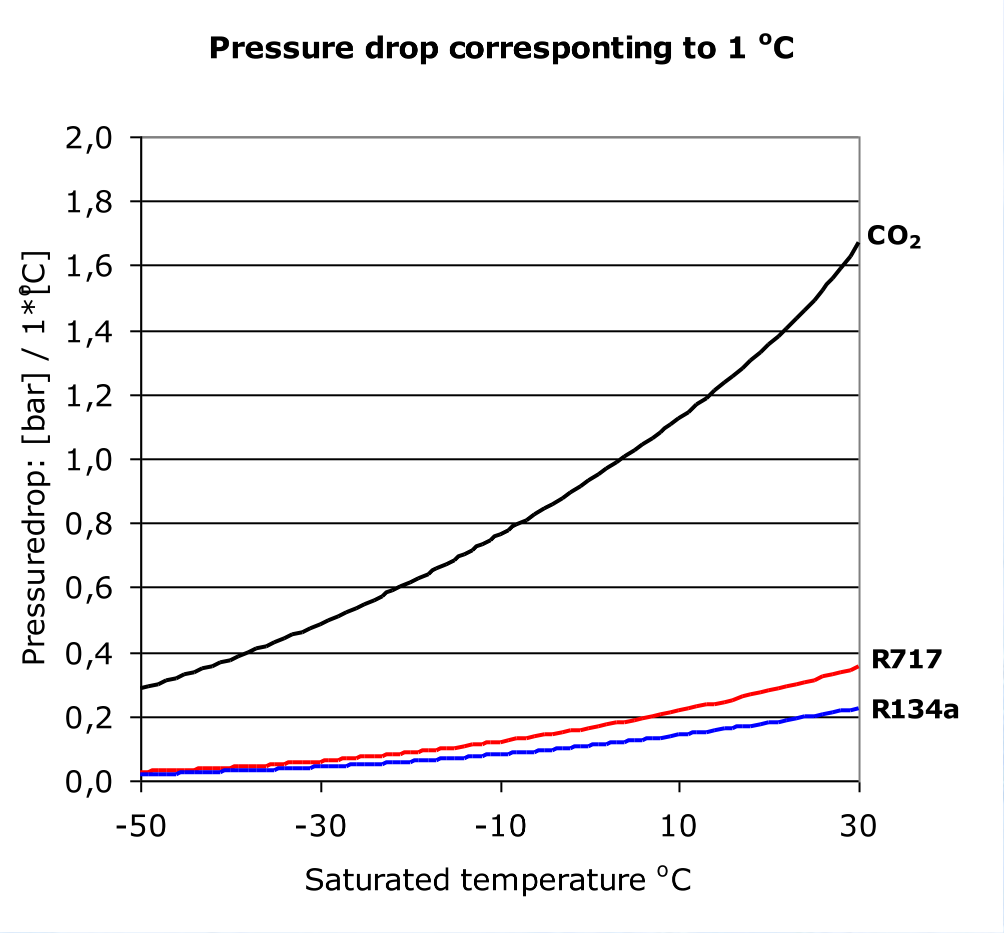
Pressure handling at Stand Still



CO_2 pressure regulator, purge to the atmosphere

Condensng unit

Pipe sizing for CO2 systems



Pressure drop in bar corresponding to 1 °C

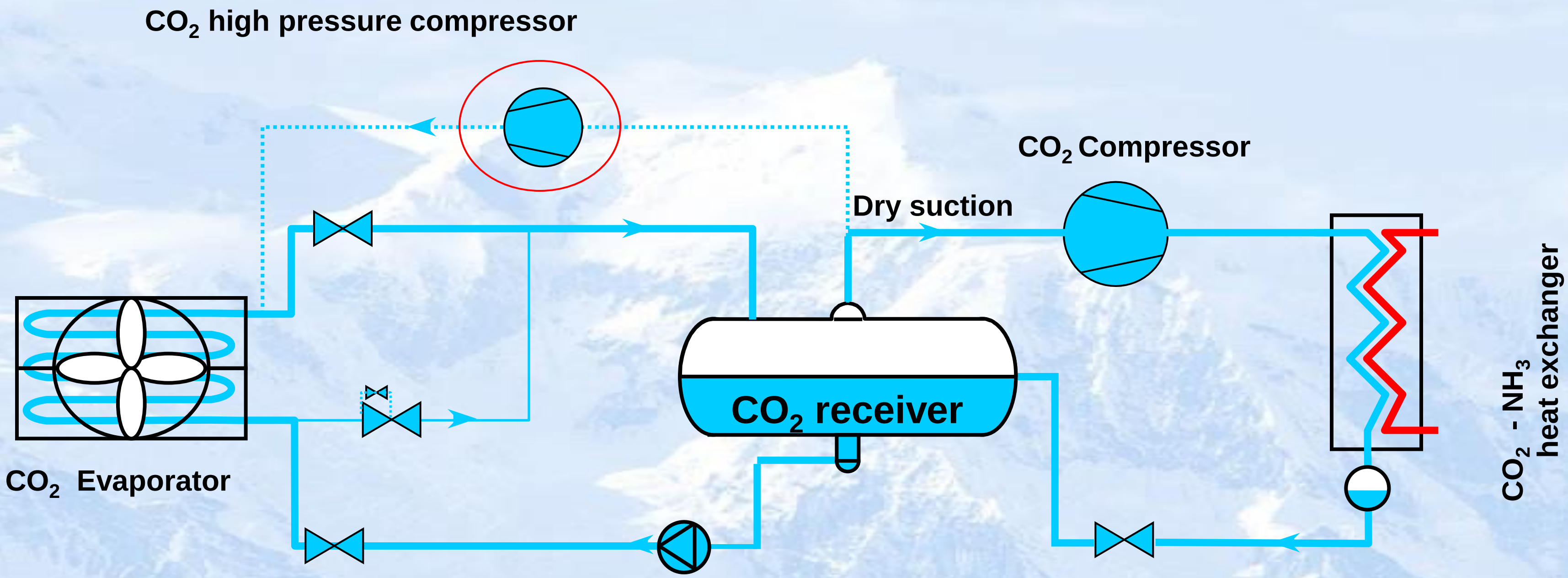
Saturated temperature [°C]	-50	-40	-30	-20	-10	0	10
Pressure drop [bar] / [°C]	0,283	0,375	0,485	0,614	0,761	0,930	1,124

Defrosting

- Most typical defrosts for CO_2 brine systems:
  - Electrical (similar to standard brines)
  - Brine defrost (additional system)
  - Water defrost (drain required)
  - Hot gas defrost (requires additional vessel and HE heated by HP stage)

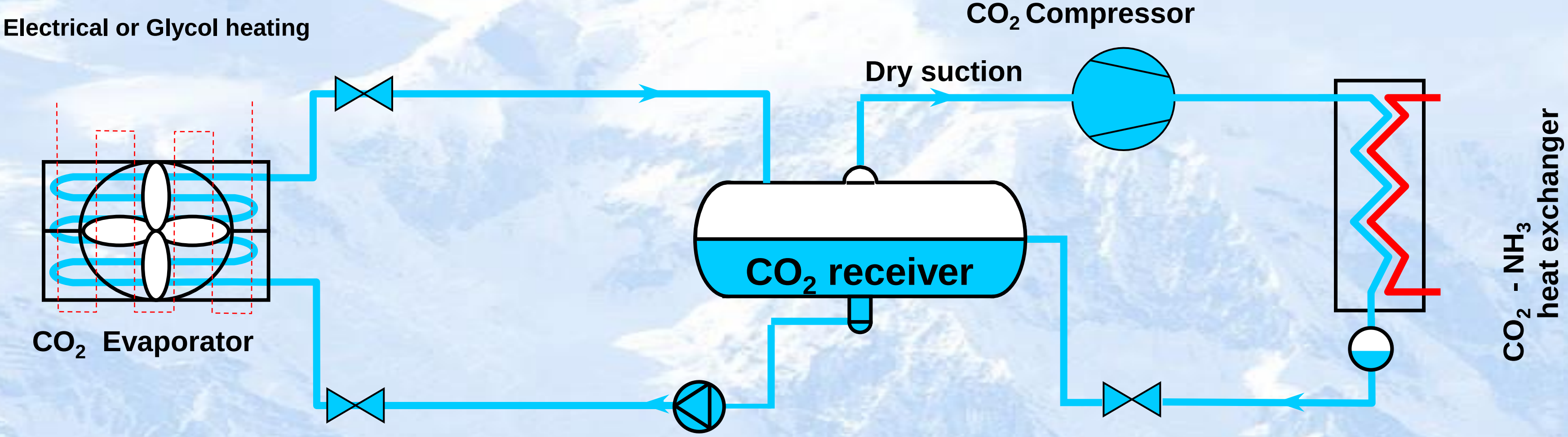
Principle diagram: CO_2-NH_3 cascade system

Hot gas defrosting – CO_2 high pressure compressor

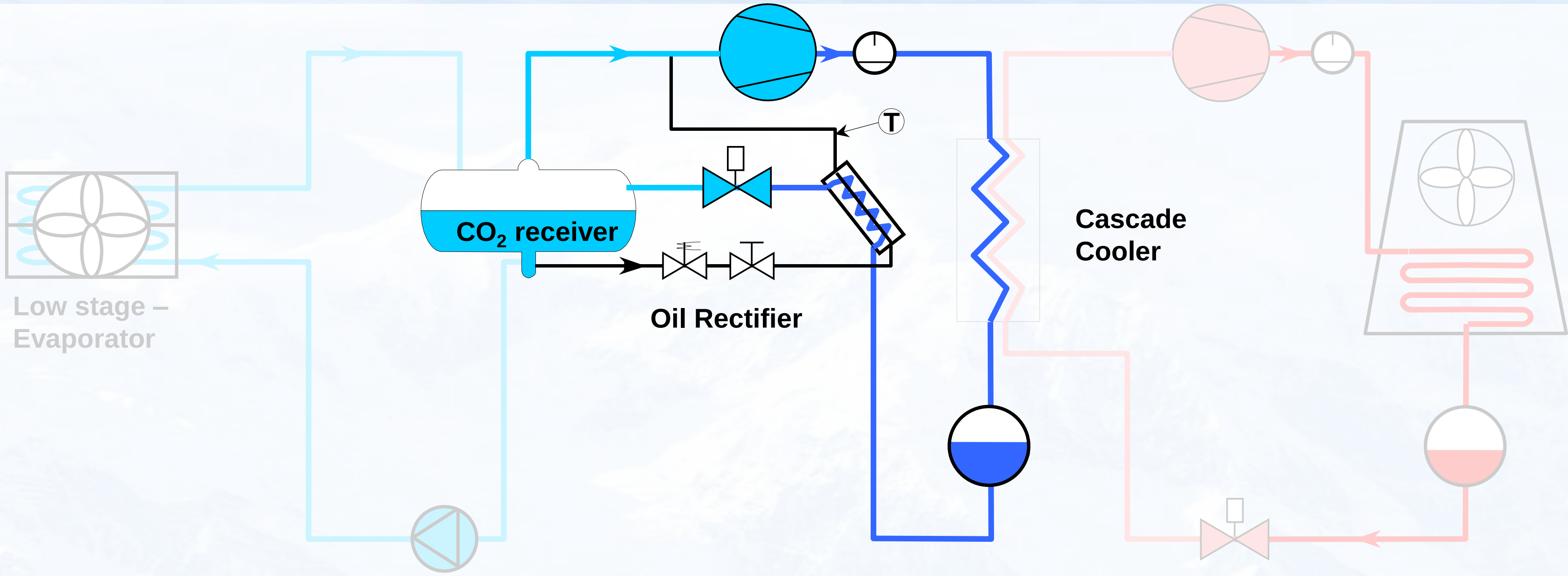


Principle diagram: CO_2-NH_3 cascade system

"Other" defrosting methods

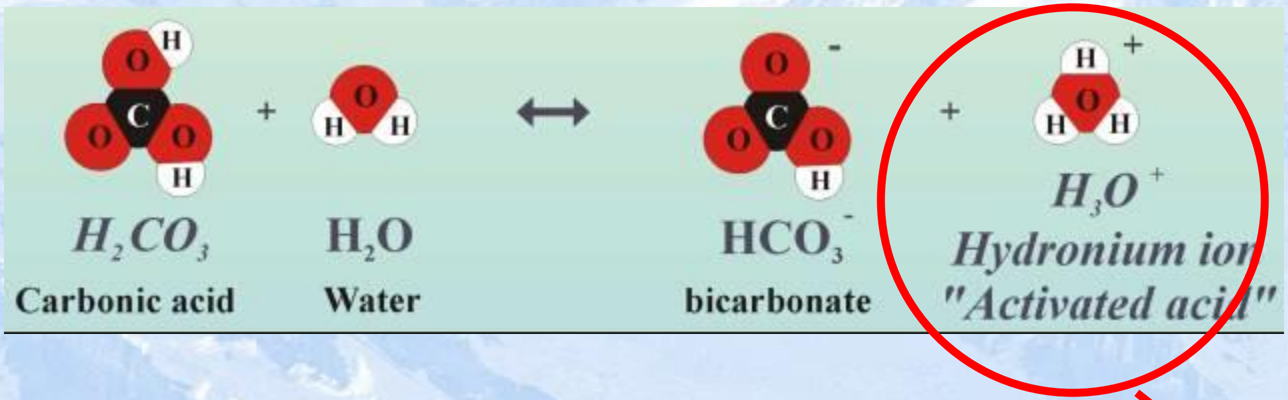


Oil management system for systems with soluble (miscible) oils



<u>Water</u> in CO_2 systems

If water is present in CO_2 systems, water reacts with CO_2 and creates <u>Carbonic acid</u>.



The concentration is depending on the water content

<u>Strong acid</u>

Toxicity and safety precautions in CO_2 systems Industrial Refrigeration

Classification

- Natural substance

Refrigerant classified as <u>non-toxic</u> and <u>non- flammable</u> fluid

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Table 1
Refrigerant classifications and quantities
(See Clauses 4.3.2, 4.4.1, 4.5.2, and 4.6.2.)

Refrigerant number		Chemical formula	Quantity of refrigerant per occupied space*				
			kg/m³†	Vol. %	lb/1000 ft³†	Limited by‡	TLV®/ TWA§
Group A1, Single Fluid							
R-11	Trichlorofluoromethane	CCl_3F	0.0256	0.40	1.6	Cardiac	1000
R-12	Dichlorodifluoromethane	CCl_2F_2	0.1920	4.00	12.0	Cardiac	1000
R-13	Chlorotrifluoromethane	$CClF_3$	0.2976	6.91	18.6	Oxygen	1000
R-13B1	Bromotrifluoromethane Halon 1301	$CBrF_3$	0.3520	5.70	22.0	Cardiac	1000
R-14	Tetrafluoromethane Carbon tetrafluoride	CF_4	0.2528	6.91	15.8	Oxygen	—
R-22	Chlorodifluoromethane	$CHClF_2$	0.1504	4.20	9.4	Cardiac	1000
R-23	Fluoroform	CHF_3	0.2000	6.91	12.5	Oxygen	1000
R-113	Trichlorotrifluoroethane	CCl_2FCClF_2	0.0304	0.40	1.9	Cardiac	1000
R-114	Dichlorotetrafluoroethane	$CClF_2CClF_2$	0.1504	2.10	9.4	Cardiac	1000
R-124	1-Chloro-1,2,2,2-tetrafluoroethane	$CHClFCF_3$	0.1136	2.00	7.1	Cardiac	1000
R-134a	1,1,1,2-Tetrafluoroethane	CH_2FCF_3	0.2064	6.00	12.9	Cardiac	1000
R-744	Carbon dioxide	CO_2	0.0912	5.00	5.7	IDLH	5000

Safety aspects

	NH_3	CO_2
TLV (Threshold Limit Value)	25 ppm	5.000 ppm
STEL (Short Term Exposure Limit)	35 ppm	30.000 ppm
Revised IDLH (Immediately Dangerous to Life and Health)	500 ppm	40.000 ppm
LFL (Lower Flammable Limit)	15%	Non Flammable
Group (ASHREA, 1992)	B2 - Toxic	A1 – Non Toxic

Ref: NIOSH

Safety Aspects of CO_2

Carbon dioxide replaces air, and causes lack of oxygen. At presence of sufficient oxygen, CO2 has a narcotic effect at stronger concentration. With smaller amounts, CO2 has a stimulating effect on the respiratory center. Due to the acidic characteristics of CO2, a certain local irritating can appear, particularly on the mucous membrane of nose, throat and eyes as well as induce coughing. The symptoms associated with the inhalation of air containing carbon dioxide are, with increasing carbon dioxide concentrations.

The data, valued for adults with good health, are as follows:

- **0,04%** Concentration in the atmospheric air
- **2%** 50% increase in breathing rate
- **3%** 10 Minutes short term exposure limit; 100% increase in breathing rate
- **5%** 300% increase in breathing rate, headache and sweating may begin after about an hour (Com.: this will tolerated by most persons, but it is physical burdening)
- **8%** Short time exposure limit
- **8-10%** Headache after 10 or 15 minutes. Dizziness, buzzing in the ears,blood pressure increase, high pulse rate, excitation, and nausea.
- **10-18%** After a few minutes, cramps similar to epileptic fits, loss of con-sciousness, and shock (i.e.; a sharp drop in blood pressure) The victims recover very quickly in fresh air.
- **18-20%** Symptoms similar those of a stroke.

SUMMARY

- **CO_2 is a natural non-toxic/non-flammable substance**
- **CO_2 is a relative unreactive refrigerant**
- **The acceptable water content in CO_2 systems is <u>much lower</u> than in other refrigeration systems.**
- **“All” reaction involving CO_2 need water to take place.**
- **Controlling the water content in CO_2 systems are very important and efficient way to avoid reaction with CO_2**
- **Water, oxygen, oxides, oil, contaminants and system metals are the most important chemical reactants. Also in systems with CO_2.**

Conclusion on CO_2 Technologies

Potential applications with CO_2 technology in medium to larger commercial and industrial systems

- Sub-critical cascade systems / secondary fluid in large commercial and industrial refrigeration
  - Technology already implemented with great results
- Trans-critical applications e.g. in supermarkets and rinks
  - Numerous installation in supermarket , very promising results on 6 rinks actually in services
  - Issues: Demanding compressor & component technologies, COP (EER) at high ambient conditions, pressure levels, discharge temperatures, more complex system technology & control

Conclusion on CO_2 Technologies

Potential applications with CO_2 technology in medium to larger commercial and industrial systems

- Hot water heat pumps & systems for drying processes
  - Domestic hot water heat pumps and district heating projects
    - Already series production in Asia
  - Medium to larger systems already in use in Canada and US and developing
  - In general ⇨ favourable conditions with CO_2
    - High gas cooler inlet & low outlet temperatures
    - High COP due to large enthalpy difference

Finally, CO2 appears to be an excellent and efficient solution to HFC replacement and adress the security and safety concerns of ammonia instalations