High
Efficiency
Solutions.

CAREL

Everything for CO_2 retail applications

Compendium

Introduction

The choice of the type of refrigerant and the type of system are fundamental in reducing emissions and protecting the environment, while energy consumption and efficiency are key criteria that have had an impact on commercial refrigeration in recent years.
Currently, CO_2 is the most marketed natural refrigerant in centralised systems. The purpose of this compendium is therefore to review certain key concepts relating to carbon dioxide, offering an overview of what are currently the most common types of CO_2 systems

Despite already having been utilised in the early 1900s, carbon dioxide has only become widely used as a refrigerant in recent years. This is due to increasing interest in natural fluids, as well as legislation that, especially in Europe, aims to limit the use of synthetic refrigerants. Widely available, even as a waste product from other processes, CO_2 is much less expensive than traditional refrigerants. Together with this economic advantage are other benefits, such as low global warming potential (GWP =1, no impact on the ozone layer), no dangers relating to toxicity or flammability, and no need to recycle the gas at the end of system life.

As well as the economic, political and environmental advantages listed above, CO_2 has several thermodynamic properties that in many different applications can represent advantages and allow it to compete head-to-head with traditional refrigerants.

The main difference between carbon dioxide and synthetic fluids is that the critical point is 31.1 °C, a temperature that is easily reached in many different parts of the planet. At critical point, the density of the liquid and saturated gas are the same, while at higher temperatures there is no longer a boundary between the two phases, and this is referred to as supercritical state. Consequently, pressure and temperature are no longer related, meaning measures need to be adopted to keep these under control, optimise heat exchange and maximise efficiency.

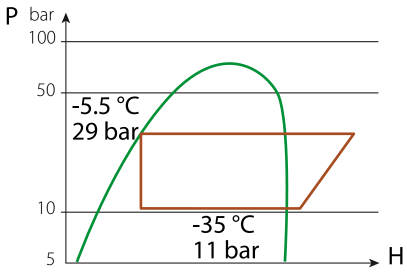
It can also be noted that operating pressures are very high, and this represents the biggest challenge for the components in the installation, such as compressors, valves and piping. Nonetheless, it should be stressed that high pressure means smaller diameter pipes can be used, and pressure drop and compression ratio are lower.
One property of CO_2 is high volumetric latent heat, giving an important advantage as concerns the heat exchangers, the number of circuits and refrigerant charge.

Types of cycle

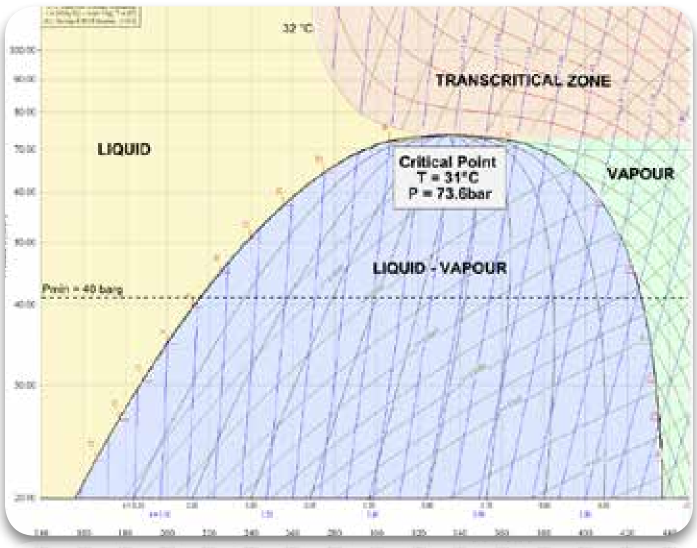
Literature gives the critical temperature for CO_2 as around 31°C (87°F), while the critical pressure, again approximately, is 73 barg (1045 psig).
CO_2 systems operate in different ways according to whether they work above or below the critical point; in essence, in a subcritical system the temperature of the CO_2 in the isothermal stage following compression of the fluid is below critical temperature, while in a transcritical system the temperature of the CO_2 at the gas cooler outlet is above 31°C, and obviously evaporation temperature is lower.

Subcritical cycle

The simplest application of carbon dioxide as a refrigerant is in the subcritical cycle: CO_2 is used in a secondary low temperature loop, either vapour compression (cascade system) or a pumped loop of liquid CO_2.



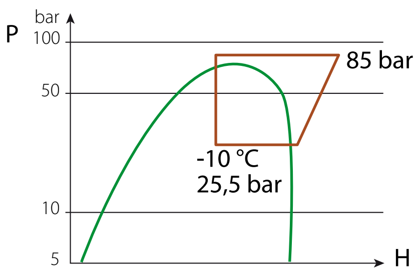
subcritical refrigeration process



The primary cycle is managed using a traditional refrigerant, with the task of keeping condensing temperature for the CO_2 cycle below the critical point, generally between -5 and -10 °C.

Transcritical cycle

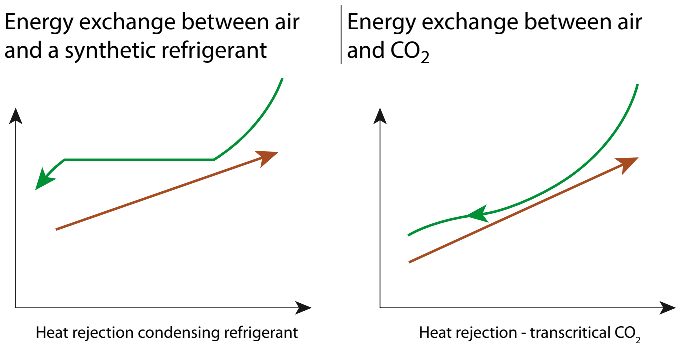
A CO_2 cycle that exchanges heat with the outside can also be adopted. This is referred to as the transcritical cycle, as in certain periods of the year outside temperature will be near or above the critical point of 31.1 °C.



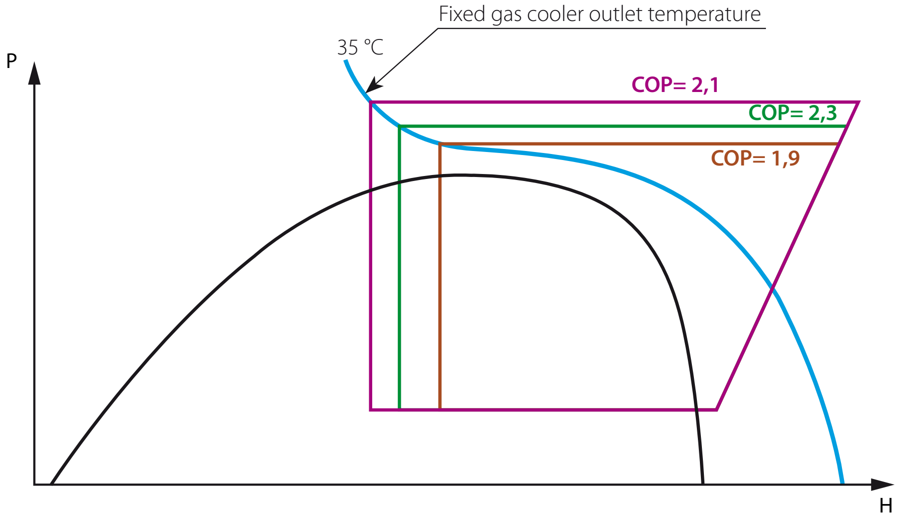
transcritical refrigeration process

Heat recovery in Booster applications

The main difference compared to a normal refrigeration cycle involves the stage in which the compressed gas is cooled, which does not correspond to constant condensing temperature as in the case of traditional cycles.



Condensation normally takes place at constant pressure, with the gas changing to the liquid phase, while in a transcritical cycle, the temperature of the supercritical gas falls constantly.
As a result, the high pressure heat exchangers used are designed differently and in fact are called gas coolers rather than condensers.
Heat exchange is assisted by this specific property of carbon dioxide, as in every phase of the cycle the two fluids are much closer in temperature than with traditional condensation. This advantage can be effectively exploited on heat pumps to achieve higher efficiency than traditional units.
As regards the efficiency of the actual cycle itself, pressure at the gas cooler outlet needs to be controlled.
Observing the p-h diagram, for a given gas cooler outlet temperature (shown in blue in the figure), different cycles can be considered based on heat exchanger pressure. It can be seen that, starting from the cycle drawn in brown and increasing the pressure, there is an increase in output (ΔhEVAP) that exceeds the increase in compression work (ΔhCOMP): efficiency is therefore higher. On exceeding the cycle pressure shown in green, the increase in compression work exceeds the increase in cooling output, meaning a reduction in efficiency (cycle drawn in violet).
Therefore, for each gas cooler outlet temperature an optimum pressure can be identified that maximises cycle efficiency.



Changes in COP at constant temperature on the PH chart

Subcritical CO_2, cascade

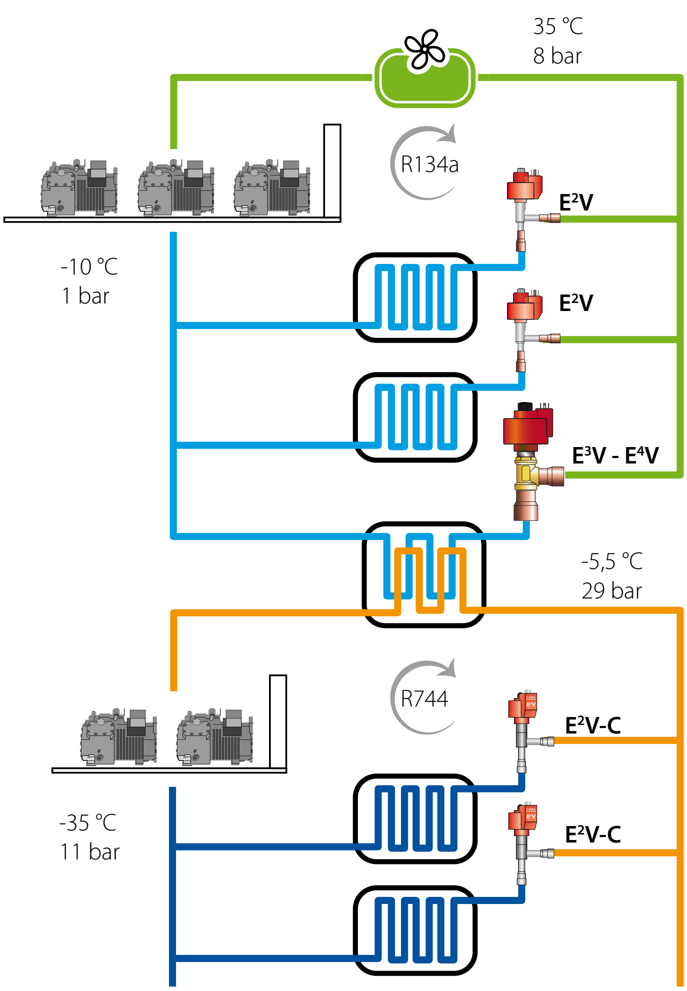
In subcritical cascade systems, CO_2 is used as the refrigerant for the low temperature stage (compressor suction temperature -30/-35°C). The heat from condensation of the CO_2 is absorbed by the refrigerant in the medium temperature stage. This process takes place via a cascade heat exchanger between the two refrigerants.

This solution is ideal for using a natural refrigerant in places with high average temperatures; subcritical CO_2 cascade systems are normally used in hot climates or as the first stage in using CO_2 as refrigerant. Cascade systems comprise two circuits, one medium temperature (typically R134a, R404a or NH3) and one low temperature (R744), connected via one or more heat exchangers, normally plate exchangers, which on one side condense the CO_2 and on the other act as normal evaporators for the medium temperature circuit.

Advantages and critical situations

- System relatively similar to a traditional installation (R404);
- Operating pressure similar to traditional systems (max 45 barg);
- Medium HFC gas content;
- System efficiency better than standard HFC and can be used in all climates.

- If NH3 is not used, the installation is not completely green;
- If NH3 is used, the medium temperature compressor rack cannot be used in all countries to serve the medium temperature showcases;
- More attention to working pressure in the secondary circuit.



example of a subcritical CO_2 cascade system

CAREL solution

List of controllers:

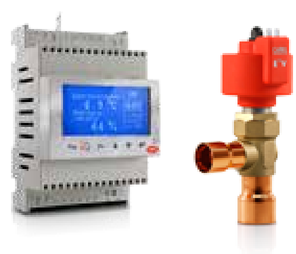
- pRack pR300 + EXV for compressor racks and plate heat exchangers;
- MPXPRO + E2V for showcases;
- EVDEVO + Ultracap for valve safety

pRack pR300 - compressor rack controller

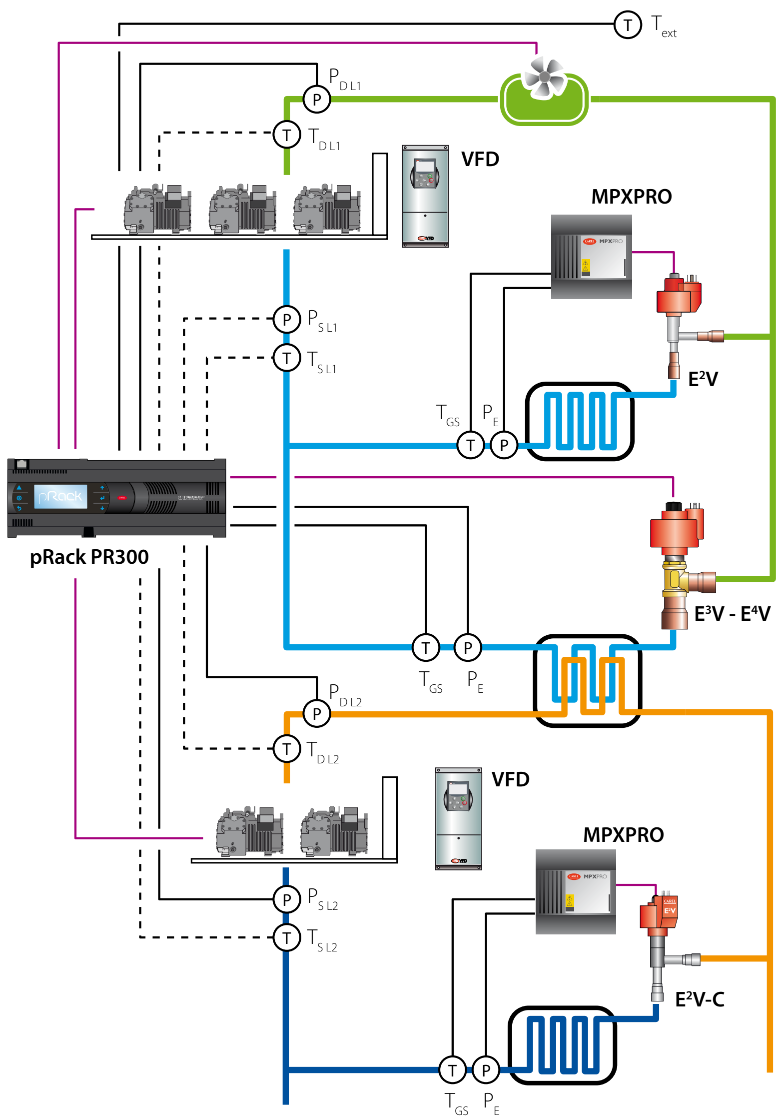
pRack pR300 manages both the medium temperature and low temperature compressor racks, with one or more controllers, depending on rack dimensions. One instrument alone can manage LT and MT compressor activation and safety (inverters, capacity control and compressors with different capacities), medium temperature condensers (EC fans, inverters, steps), any subcooling systems, synchronisation between the two systems and communication with the electronic expansion valve driver on the cascade system heat exchanger.
At most two plate heat exchangers are normally used to condense the CO_2, and the expansion valve can be managed using the built-in driver on pRack pR300 or an external EVD EVO driver integrated into the system (RS485 fieldbus communication).

EVDEVO driver - control of expansion valves

The crucial aspect of this type of installation is the cascade heat exchanger, normally a plate heat exchanger, that condenses the CO_2. Two heat exchangers are sometimes used in order to improve control at low loads and increase safety, and are normally controlled by EXV stepper electronic expansion valves (in these applications PWM electronic valves cannot guarantee optimum performance).
In such applications, as well as traditional suction superheat control, there is direct integration with the low temperature compressor rack if the driver is built into the controller, or via serial communication if an external EVD EVO driver is used.
Due to the nature of the refrigerant, the condensed liquid CO_2 needs to be monitored to ensure good performance.



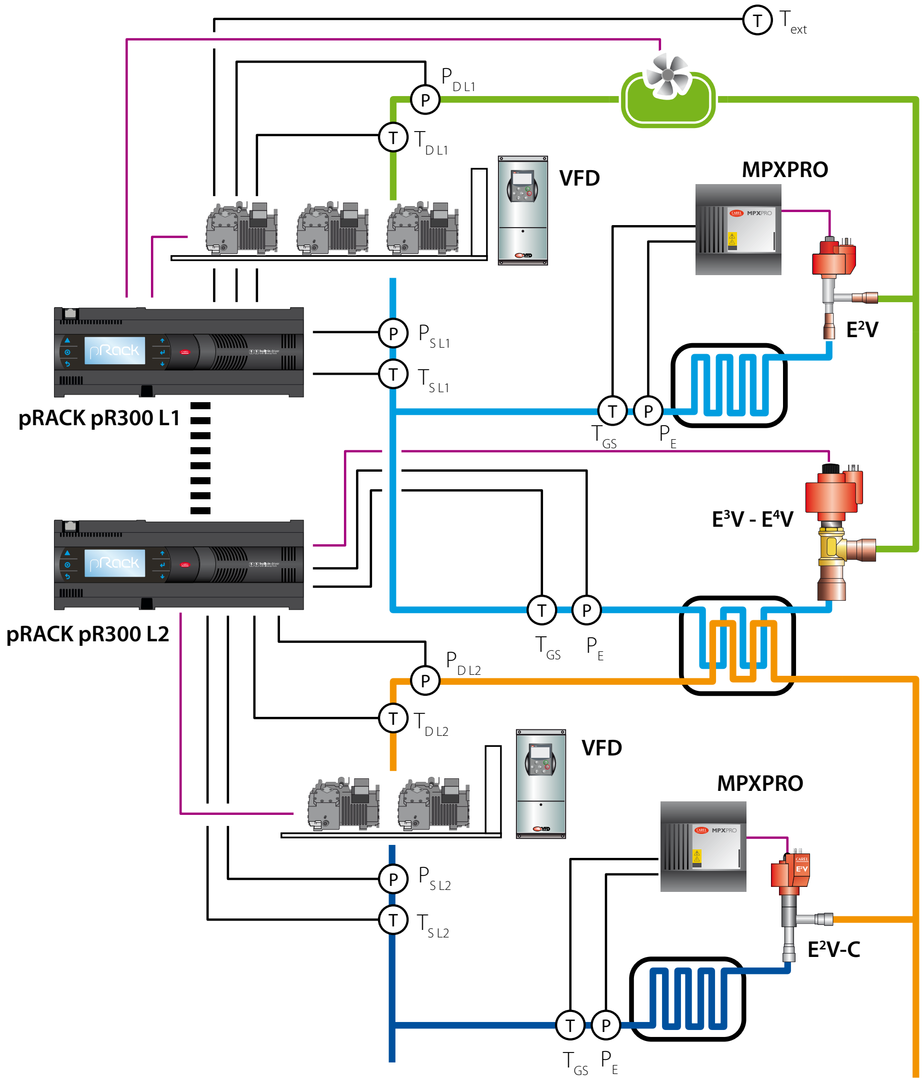
Control diagram with one pRack board and one built-in driver



pRack connections

symbol	description	probe type
T_{ext}	Outside temperature	NTC - HP
P_{DL1}	Line 1 (medium temperature) discharge pressure	4-20 mA 0-18.2 barg
T_{DL1}	Line 1 (medium temperature) discharge temperature	NTC – HF (For discharge temperature control (optional))
P_{SL1}	Line 1 (medium temperature) suction pressure	4-20 mA 0-7 barg (Can be used as backup for PE)
T_{SL1}	Line 1 (medium temperature) suction temperature	NTC – HF (For suction superheat control (optional))
P_E	Heat exchanger evaporation pressure	Ratiometric -1-9.3 barg
T_{GS}	Heat exchanger superheated gas temperature	NTC – HF
P_{DL2}	Line 2 (low temperature) discharge pressure	4-20 mA 0-44.8 barg
T_{DL2}	Line 2 (low temperature) discharge temperature	NTC – HF For discharge temperature control (optional))
P_{SL2}	Line 2 (low temperature) suction pressure	4-20 mA 0-44.8 barg
T_{SL2}	Line 2 (low temperature) suction temperature	NTC – HF (For suction superheat control (optional))

Control diagram with two pRack boards and one built-in driver



pRack connections for L1

symbol	description	probe type
T_{ext}	Outside temperature	NTC - HP
P_{DL1}	Line 1 (medium temperature) discharge pressure	4-20 mA 0-18.2 barg
T_{DL1}	Line 1 (medium temperature) discharge temperature	NTC – HF (For discharge temperature control (optional))
P_{SL1}	Line 1 (medium temperature) suction pressure	4-20 mA 0-7 barg (Can be used as backup for PE)
T_{SL1}	Line 1 (medium temperature) suction temperature	NTC – HF (For suction superheat control (optional))

symbol	description	probe type
P_E	Heat exchanger evaporation pressure	Ratiometric -1-9.3 barg
T_{GS}	Heat exchanger superheated gas temperature	NTC – HF
P_{DL2}	Line 2 (low temperature) discharge pressure	4-20 mA 0-44.8 barg
T_{DL2}	Line 2 (low temperature) discharge temperature	NTC – HF (For discharge temperature control (optional))
P_{SL2}	Line 2 (low temperature) suction pressure	4-20 mA 0-44.8 barg
T_{SL2}	Line 2 (low temperature) suction temperature	NTC – HF (For suction superheat control (optional))

System features

DSS: Double system synchronization

System for communication between the medium temperature and low temperature compressor racks.

The low temperature circuit cannot operate correctly if the medium temperature circuit is not working, therefore communication between the two systems is essential to synchronise operation and modify operation when needed.

Specifically, the following are possible:
- start the medium temperature rack when the low temperature rack is operating, both during start-up and in normal operation;
- shut down the low temperature rack when the medium temperature rack is not working correctly;
- avoid simultaneous compressor starts on the different systems to reduce peaks in energy consumption;
- pump-down on the medium-temperature compressor rack when at least one compressor on the low-temperature rack is operating

EEVS: Electronic Expansion Valve Synchronization

System for communication between the low temperature rack (pRack pR300) and electronic expansion valve driver on the plate heat exchanger, either built-in on pRack pR300 or external (EVD EVO).

The low temperature rack can in this case tell the driver of any changes in cooling capacity and thus modulate evaporator capacity based on CO_2 condensing pressure, without requiring additional probes and ensuring fine and precise condensing pressure control. Exchanging information between the compressor rack and the heat exchanger can also augment traditional superheat control with factors that are vital for this type of installation, such as variation in low temperature rack cooling capacity and trend in CO_2 condensing pressure.

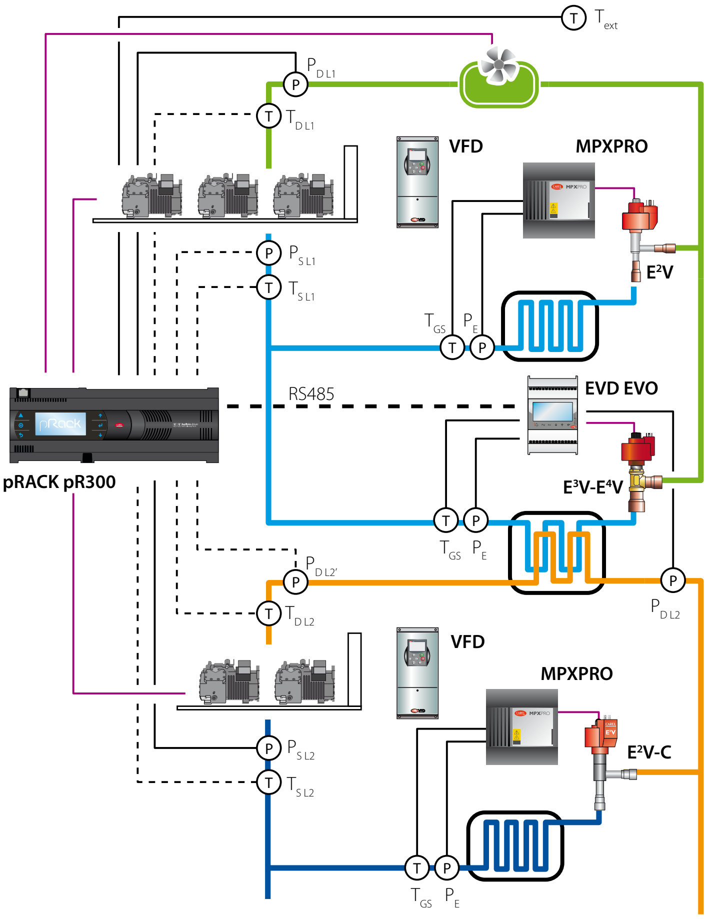
This function can be used in the following configurations:
- pRack pR300 with built-in driver and just one heat exchanger
- pRack pR300 with one individual external EVD EVO driver
- pRack pR300 with two individual external EVD EVO drivers;
- pRack pR300 with two EVD EVO drivers: one built-in driver (one heat exchanger) and one individual external

Reverse high condensing temperature protection (HiTcond) on S3

Safety procedure activated by connecting the condensing pressure probe directly to the EVD EVO driver (external or built-in); in this way, valve control will be directly influenced by a safety procedure that tends to open the valve when CO_2 condensing pressure is too high. In this case, CO_2 condensing pressure relating to the pRack becomes optional.

The aim of HiTCond reverse protection is to quickly limit increases in condensing pressure in the CO_2 circuit possibly due to variations in load, operating conditions, unstable the compressor control and generic problems caused by a sudden increase in valve opening.

Control diagram with one pRack board and one individual external driver featuring high CO_2 pressure protection



pRack connections

symbol	description	probe type
T_{ext}	Outside temperature	NTC - HP
P_{DL1}	Line 1 (medium temperature) discharge pressure	4-20 mA 0-18.2 barg
T_{DL1}	Line 1 (medium temperature) discharge temperature	NTC – HF (For discharge temperature control (optional))
P_{SL1}	Line 1 (medium temperature) suction pressure	4-20 mA 0-7 barg (Can be used as backup for PE)
T_{SL1}	Line 1 (medium temperature) suction temperature	NTC – HF (For suction superheat control (optional))
$P_{DL2'}$	Line 2 (low temperature) discharge pressure	4-20 mA 0-44.8 barg (Can be used as backup for PD L2)
T_{DL2}	Line 2 (low temperature) discharge temperature	NTC – HF (For discharge temperature control (optional))
P_{SL2}	Line 2 (low temperature) suction pressure	4-20 mA 0-44.8 barg
T_{SL2}	Line 2 (low temperature) suction temperature	NTC – HF (For suction superheat control (optional))

EVD EVO connections

symbol	description	probe type
P_{DL2}	Line 2 (low temperature) discharge pressure	4-20 mA 0-44.8 barg
P_E	Heat exchanger evaporation pressure	Ratiom. -1-9.3 barg
T_{GS}	Heat exchanger superheated gas temperature	NTC – HF

Subcritical CO_2, pumped

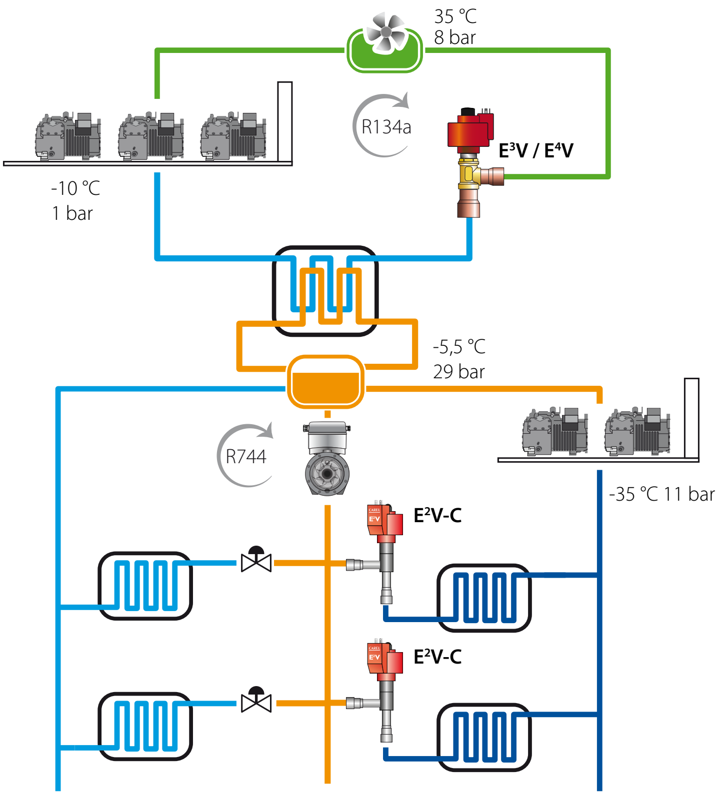
In subcritical pumped systems, CO_2 is used as the refrigerant for both stages (if featured), low and medium temperature. In these systems, CO_2 is a secondary refrigerant, and the primary circuit, typically a chiller using HFCs/HCs, has the task of cooling the liquid CO_2, which is then pumped inside the system; this process also takes place via a heat exchanger, with the addition of a liquid receiver and a pump.

Not as widely used as traditional cascade subcritical systems, these aim to limit the use of HFC refrigerants only to the equipment room. The medium temperature showcases are supplied with pumped liquid CO_2 while the low temperature showcases are fitted with expansion valves. The CO_2 is cooled by a dedicated chiller (NH3 or R134a) inside a tank, normally with a tube bundle evaporator.
In addition to traditional systems, these also include pumps that circulate the liquid CO_2 to the medium temperature evaporators, where it is not expanded, but rather is simply superheated, returning to the receiver in the semi-liquid phase.

Advantages and critical situations

- low non-natural refrigerant content;
- possibility to use ammonia (NH3), limited to the equipment room only;
- completely green installation inside the store display area.

- very sensitive to pumping system piping size;
- additional pump energy consumption;
- more attention to working pressure in the secondary circuit.



example of pumped subcritical CO_2 system

CAREL solution

List of controllers:

- pRack pR300 + EXV for compressor racks and tube bundle evaporator;
- MPXPRO + E2V for showcases;
- MPXPRO light for medium-temperature showcases;
- EVDEVO + Ultracap for valve safety

pRack pR300 - compressor rack controller

This manages both the chiller compressors - based on the CO_2 pressure inside the receiver - and the low temperature compressors, applying the same synchronisation functions between the two systems. One important aspect in this type of system is coordinated operation of the medium temperature rack with the tube bundle evaporator controller, to prevent problems of low pressure.
Receiver pressure control is the main task, given the quantity of refrigerant inside and consequently its significant inertia, and therefore it is essential to activate the compressors based on receiver pressure; medium temperature compressor suction pressure will therefore only be monitored for safety reasons, to prevent problems of low pressure.
pRack can also manage simple pumping systems with or without inverter.

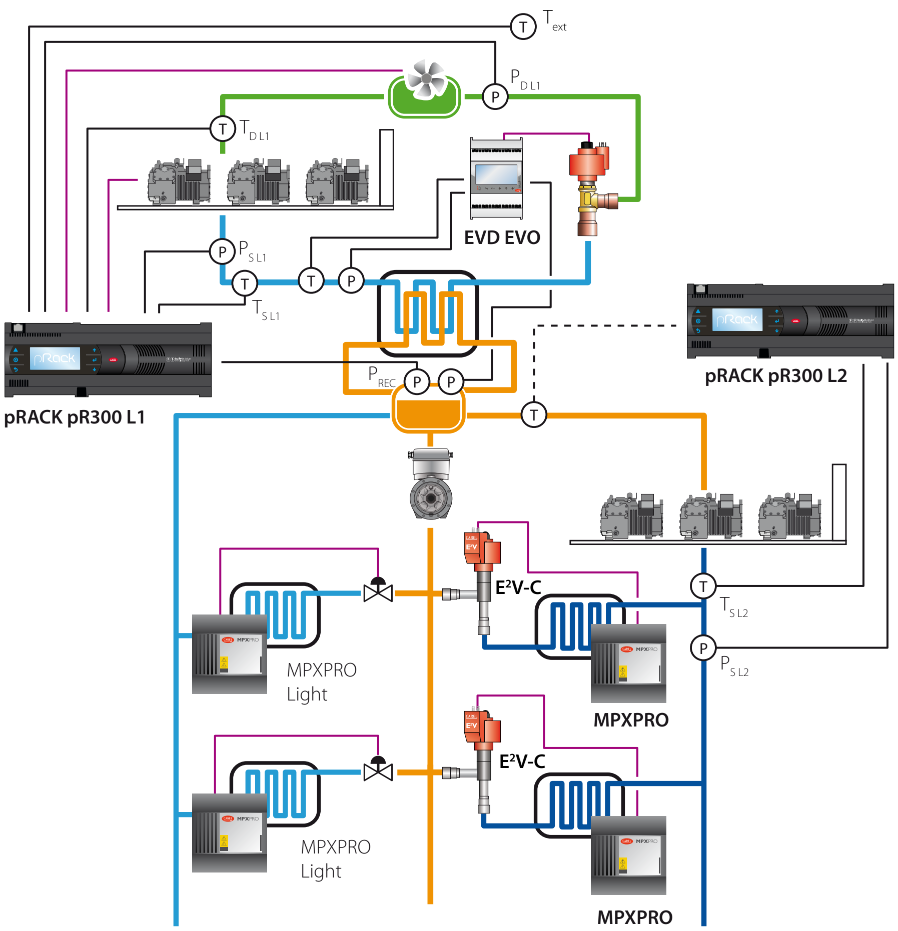
MPXPRO and MPXPRO light

MPXPRO for low temperature units with electronic expansion valve, and for medium temperature units thanks to a new function that allows a stepper valve to be used to control refrigerant flow. Alternatively, MPXPRO light can be used on medium temperature units that do not require the use of an electronic expansion valve, but simply management of refrigerant flow based on showcase demand.
Compatible with the full option version, MPXPRO light standardises wiring and installation.

EVD EVO driver - control of expansion valves

Management of the tube bundle evaporator is critical in this type of application, the size of the evaporator, the inertia of the load and the proximity of the compressors require very fine control that needs to adapt quickly to compressor activation or deactivation, respond gradually to changes in load, not flood the compressors and protect against low suction pressure alarms.
The functions of the EVD EVO driver and the low superheat, low suction pressure and high CO_2 condensing pressure protection must therefore be correctly calibrated based on the features of the installation (number and type of compressors, evaporator and receiver size, whether receivers are used on the suction side, system dynamics).

Control diagram with two pRack boards



pRack pR300 connections on L1

symbol	description	probe type
T_{ext}	Outside temperature	NTC - HP
$P_{D L1}$	Condensing pressure line 1 (medium temperature)	4-20 mA 0-18.2 barg
$T_{D L1}$	Line 1 (medium temperature) discharge temperature	NTC – HF (For discharge temperature control (optional))
$P_{S L1}$	Line 1 (medium temperature) suction pressure	4-20 mA 0-10 barg (For low pressure alarm control)
$T_{S L1}$	Line 1 (medium temperature) suction temperature	NTC – HF (For suction superheat control (optional))
P_{REC}	CO_2 receiver pressure	4-20 mA 0-10 barg (For medium temperature compressor control)

pRack pR300T connections on L2

symbol	description	probe type
$T_{D L2}$	Line 2 (low temperature) discharge temperature	NTC – HF (For discharge temperature control (optional))
$P_{S L2}$	Line 2 (low temperature) suction pressure	4-20 mA 0-44.8 barg
$T_{S L2}$	Line 2 (low temperature) suction temperature	NTC – HF (For suction superheat control (optional))

EVD EVO connections

symbol	description	probe type
P_{REC}	Line 2 (low temperature) discharge pressure	4-20 mA 0-44.8 barg
P_{E}	Heat exchanger evaporation pressure	Ratiometric -1-9.3 barg
T_{GS}	Heat exchanger superheated gas temperature	NTC – HF

Transcritical CO_2, booster

In transcritical systems, CO_2 is cooled but does not condense at the gas cooler outlet, being above critical temperature. A booster system is when there are two stages of compression of the same refrigerant, therefore the CO_2 discharged by the low temperature compressors flows, via a intercooler, to the suction port of the medium temperature compressors.

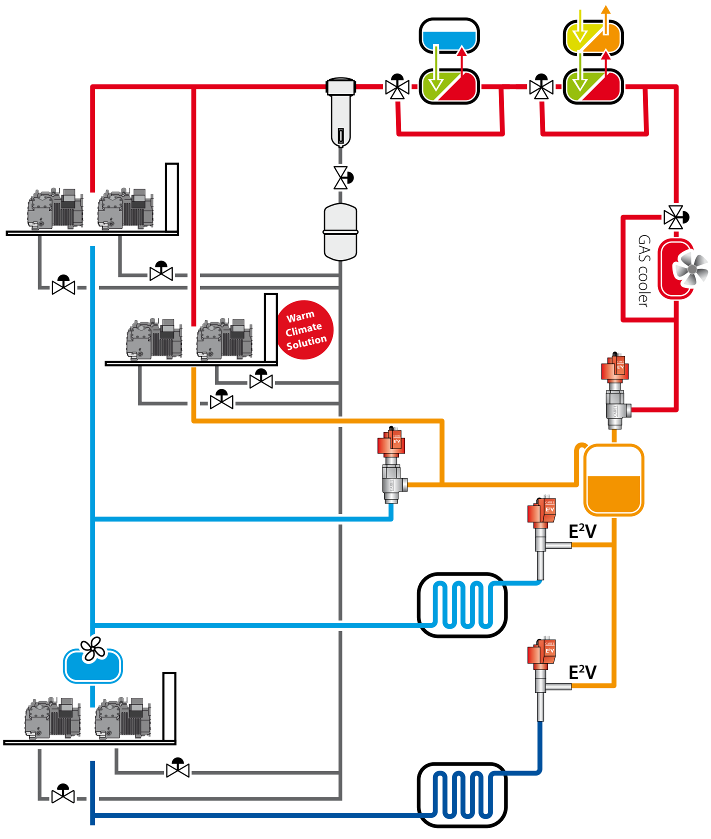
Transcritical CO_2 booster systems are the most promising solutions for using natural refrigerants in retail contexts, above all in climates that are not too hot.
They generally feature four sections with different pressures:
- high pressure: the section from the medium temperature compressor discharge to the HPV valve (in red), safety setting 130 bars;
- intermediate pressure: the section from the HPV valve to all the expansion valves (in orange), safety setting 90 bars;
- medium pressure: the section from the medium temperature evaporators downstream of the expansion valve to the suction side of the medium temperature compressors (in light blue), safety setting 60 bars;
- low pressure: the section from the low temperature evaporators downstream of the pressure regulating valves to the suction side of the low temperature compressors (in blue), safety setting 45 bars.

A basic traditional installation with parallel compressors is shown in the figure below. Different variants can be found on the market, above all using plate heat exchangers to increase system efficiency and/or assist correct operation. These are not normally part of system operating logic, and are not covered in this document.

Advantages and critical situations

- system that completely uses natural refrigerants (CO_2);
- various studies have shown higher efficiency than any other type of installation (traditional R404a or subcritical CO_2) at average outside temperatures less than 15°C;
- technology becoming standardised, costs are falling.

- high pressures involved (up to 120 barg);
- systems are normally more complex than traditional ones;
- good efficiency even in warm climates (>15 °C), using additional technology such as parallel compressors, chillBooster and heat recovery



example of a transcritical CO_2 system

In general, the gas is drawn in by the medium temperature compressors at a pressure of around 26 barg (maximum pressure 40-60 barg), and at the compressor discharge normally passes through a heat recovery system (of varying complexity), essential for overall unit efficiency, and the gas cooler. In this section, operating pressure essentially depends on outside temperature, and may vary from minimum values of around 40-45 barg, based on the type of compressors used, to 120 barg, the maximum safety valve pressure. The name gas cooler refers to the fact that, in certain climatic conditions, it may not manage to condense the CO_2, which consequently reaches the high pressure valve in the form of a dense gas. The high pressure valve (HPV) is the heart of this type of installation, making sure it works efficiently and in the most favourable conditions at any given moment; consequently, it lowers the operating pressure of the receiver downstream to 35-40 barg so as to condense the CO_2. Receiver pressure is managed by the regulating valve (RPRV), which works by bypassing the system so as to maintain constant receiver pressure.
Receiver pressure is managed by the regulating valve (RPRV) or flash gas valve, which works by bypassing some of the gas so as to maintain constant receiver pressure. From the receiver, the liquid flows to all the medium and low temperature showcases; it is then expanded by the expansion valves on the low temperature evaporators and then drawn in by the LT compressors and subsequently remixed with the gas from the medium temperature evaporators and the receiver pressure regulating valve (in this section, maximum pressure may range from 25 to 60 barg).
These gases - at different temperatures - are then drawn in by the medium temperature compressors. The most common variants include:

- intercool cooler for cooling low temperature compressor discharge (manage a second condenser line based on temperature;
- plate heat exchangers between the gas from the RPRV and the liquid line, with the dual purpose of subcooling the liquid at the evaporators and offsetting the heating effect of the RPRV valve;
- plate heat exchangers between the suction side of the medium temperature compressors and the gas cooler outlet, with the dual purpose of assisting mixing between the different gases on the compressor suction side and further cooling the gas exiting the gas cooler.

CAREL solution

List of controllers:

- pRack pR300T + ExV-C for compressor racks and high pressure valves;
- MPXPRO + E2V for showcases;
- EVDEVo + Ultracap for valve safety;
- chillBooster for evaporative cooling.

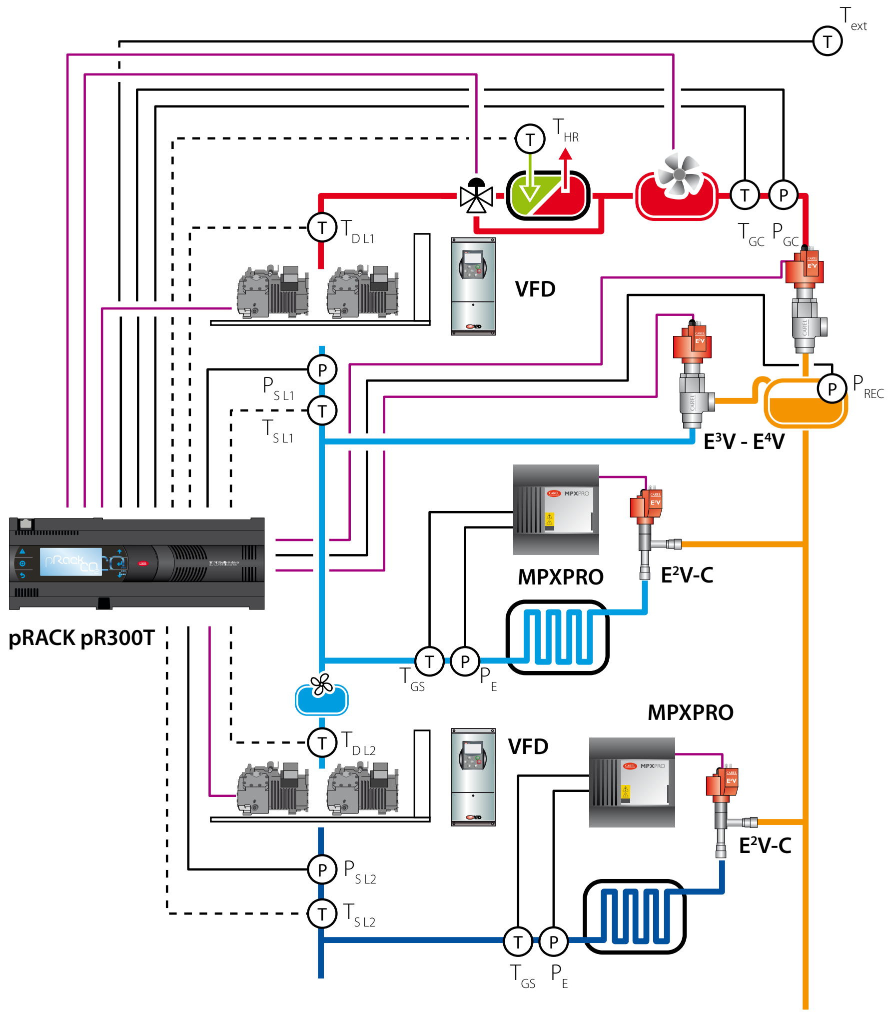
pRack pR300T: controller for transcritical CO_2 compressor racks

pRack pR300T provides complete management - in single or multi-board configurations - of both small and medium-large transcritical CO_2 systems. One instrument alone can manage LT and MT compressor activation and safety, any heat recovery systems, the gas cooler, the oil recovery system, the high pressure valve (HPV) and receiver pressure regulating valve (RPRV).
The HPV and RPRV valves can be managed directly by pRack pR300T with built-in driver or with external EVD EVO driver. Both instruments are compatible with all valves available on the market.

E3V-C: high pressure valve

Carel's consolidated experience in high-efficiency expansion valves, specifically those working with natural refrigerants, has given rise to a family of valves specifically designed for transcritical carbon dioxide (CO_2) applications, suitable for commercial and industrial refrigeration systems and the food sector in particular.
The entire EXV-C series guarantees maximum installation freedom. Freedom ensured by extremely compact dimensions (up to 30% smaller than the alternatives), the result of a patented design (patent pending), and the removable stator that, even when not powered, allows complete manual valve operation using the optional EEVMAG accessory.
The compact dimensions of the EXV-C also mean a significantly lower weight than other products currently available, simplifying installation and reducing any problems due to vibrations in the system.
Modular construction and a washable stainless steel filter further simplify installation and maintenance of the E3V-C.

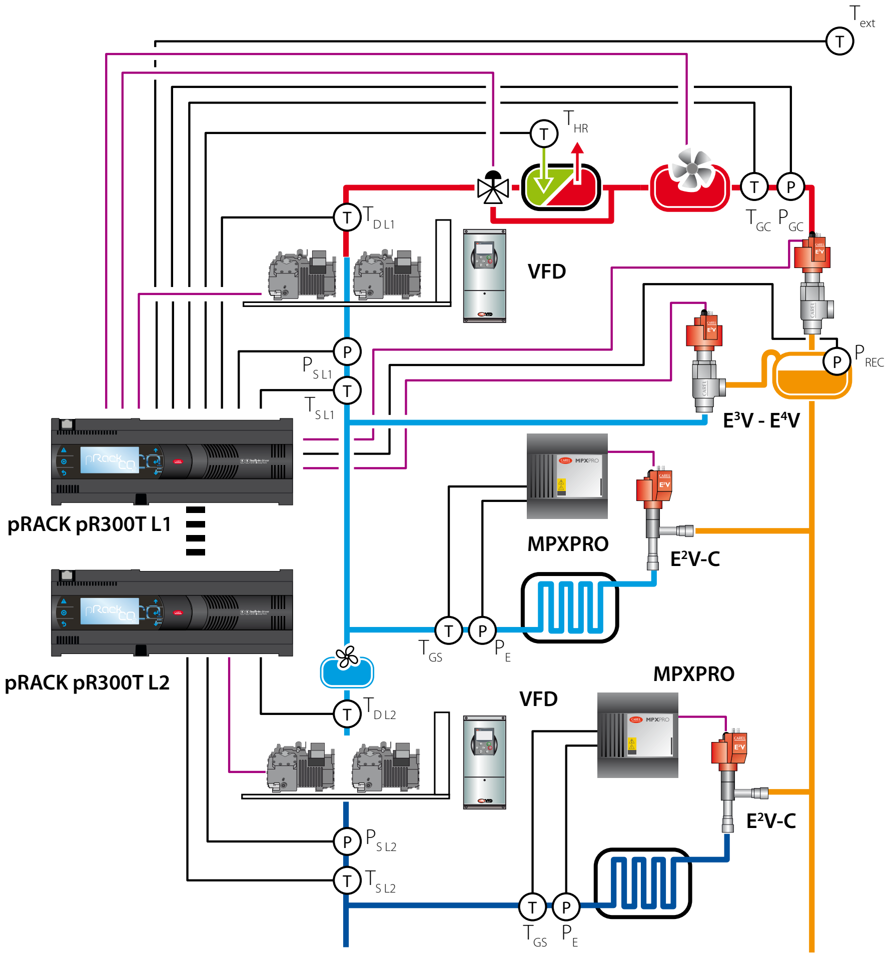
Control diagram with one pRack board and built-in twin driver



pRack pR300T connections

symbol	description	probe type
T_{ext}	Outside temperature	NTC - HP
P_{GC}	Gas cooler pressure	4-20 mA 0-150 barg
T_{GC}	Gas cooler outlet temperature	NTC - HF
T_{HR}	Heat reclaim temperature	NTC – HF (For heat recovery system control (optional))
P_{REC}	Receiver pressure	4-20 mA 0-60 barg
P_{SL1}	Line 1 (medium temperature) suction pressure	4-20 mA 0-44.8 barg
T_{SL1}	Line 1 (medium temperature) suction temperature	NTC – HF (For suction superheat control (optional))
T_{DL2}	Line 2 (low temperature) discharge temperature	NTC – HF (For discharge temperature control (optional))
P_{SL2}	Line 2 (low temperature) suction pressure	4-20 mA 0-44.8 barg
T_{SL2}	Line 2 (low temperature) suction temperature	NTC – HF (For suction superheat control (optional))

Control diagram with two pRack boards and built-in twin driver



pRack pR300T connections for L1

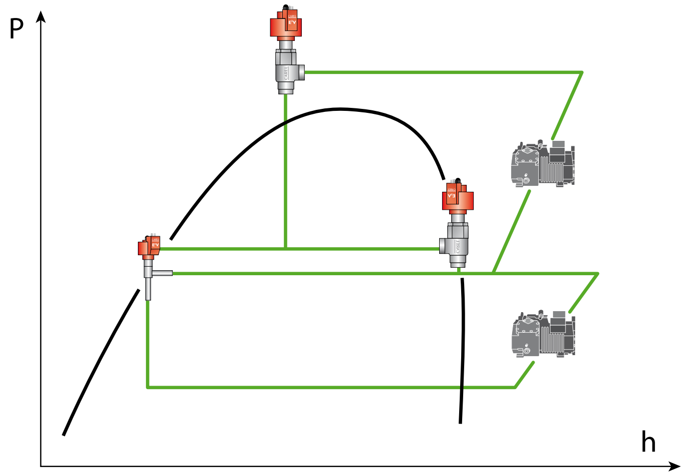
symbol	description	probe type
T_{ext}	Outside temperature	NTC - HP
P_{GC}	Gas cooler pressure	4-20 mA 0-150 barg
T_{GC}	Gas cooler outlet temperature	NTC - HF
T_{HR}	Heat reclaim temperature	NTC – HF (For heat recovery system control (optional))
P_{REC}	Receiver pressure	4-20 mA 0-60 barg
P_{SL1}	Line 1 (medium temperature) suction pressure	4-20 mA 0-44.8 barg
T_{SL1}	Line 1 (medium temperature) suction temperature	NTC – HF (For suction superheat control (optional))

pRack pR300T connections for L2

symbol	description	probe type
T_{DL2}	Line 2 (low temperature) discharge temperature	NTC – HF (For discharge temperature control (optional))
P_{SL2}	Line 2 (low temperature) suction pressure	4-20 mA 0-44.8 barg
T_{SL2}	Line 2 (low temperature) suction temperature	NTC – HF (For suction superheat control (optional))

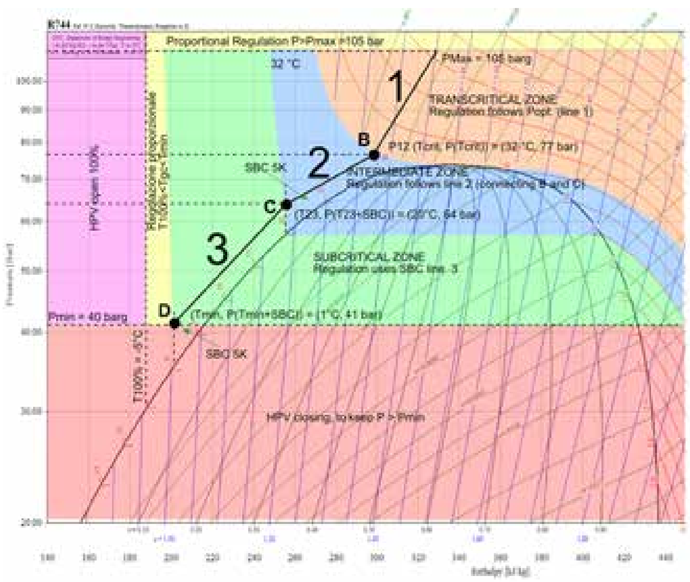
System features

Control of high pressure valves



The HPV valve control algorithm on pRack pR300T is managed based on the gas cooler outlet temperature TGC and gas cooler pressure PGC. Depending on operating conditions, the system can work in:

- transcritical operating conditions (line 1), in which the instrument controls the HPV valve so as to maintain the best set point and maximise compressor rack COP
- subcritical operating conditions (line 3), in which instrument attempts to maintain a certain level of subcooling
- transition operating conditions (line 2), in which the instrument attempts to keep the transition from transcritical to subcritical as smooth as possible, considering that the refrigerant in such situations is neither in the liquid nor gas phase.



RPRV valve management aims to maintain constant pressure inside the receiver around a set point; in extreme conditions it may modify the operating conditions of the HPV so as to ensure the system as a whole operates correctly.

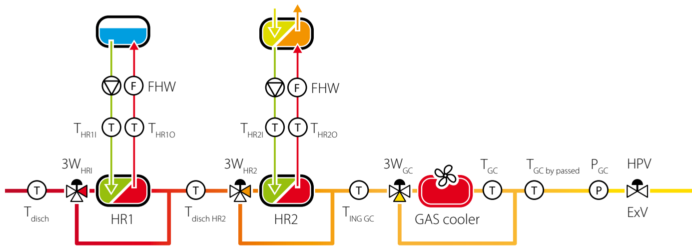
The oil recovery system manages oil levels in the separator, controls the receiver injection solenoid valve, as well as the pressure difference from compressor rack suction pressure, and also manages the injection of oil into the various compressors, with alarms triggered if injection is not sufficient.

An important factor in system operation, this function can also be used with the electromechanical oil recovery systems that are widely available on the market to simply monitor and log system operation for subsequent verification.

Heat recovery

The heat recovery system, very important for overall system efficiency, is managed so as to maximise the amount of heat recovered, adjusting the operating conditions of both the gas cooler and the high pressure valve.

The circuit correctly exploits the excess heat from the medium temperature compressor discharge when the system is in the transcritical stage, accepting a decline in COP because this is any case more efficient than using an additional unit to produce heat.



Heat recovery management allows complete control of two heat exchangers and related circulating pumps (in the case of CO_2-water) Activation and control of each heat recovery cycle is based on the percentage of heat demand, calculated using one of the following:

- digital input
- temperature probe
- external analogue signal

For the last two, a digital input can also be used to enable the function. Once active, heat recovery can adjust the HPV valve set point, increasing the minimum set point from the default value (40.0 barg) to a new minimum set point (e.g. 75.0 barg). In this way, the system operates in transcritical conditions even when operating conditions are subcritical, and the HPV set point would be calculated based on subcooling.

The set point can be increased proportionally to the increase in heat recovery demand, up to a maximum settable value (which corresponds to 100% of heat recovery demand).

The heat recovery function can also adjust the gas cooler set point, gradually increasing the temperature (or pressure) set point of the gas cooler fans either at the same time as or subsequent to the increase in the high pressure valve minimum set point.

Finally, again linked to the percentage of heat recovery demand and operating conditions, the gas cooler can also be bypassed.

expansion board for Retail applications

DSS: Double system synchronization

System for communication between the medium temperature and low temperature compressor racks.
The low temperature circuit cannot operate correctly if the medium temperature circuit is not working, therefore communication between the two systems is essential to synchronise operation and modify operation when needed.

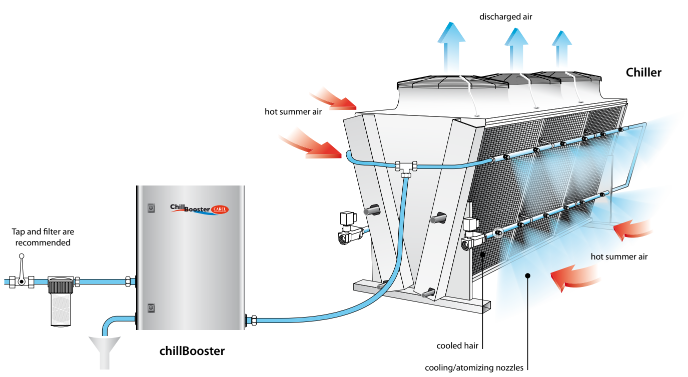
Specifically, the following are possible:

- start the medium temperature rack when the low temperature rack is operating, both during start-up and in normal operation;
- shut down the low temperature rack when the medium temperature rack is not working correctly;
- avoid simultaneous compressor starts on the different systems to reduce peaks in energy consumption;
- enable pump-down on the medium-temperature compressor rack when at least one compressor on the low-temperature rack is operating.

Solutions for mild climates

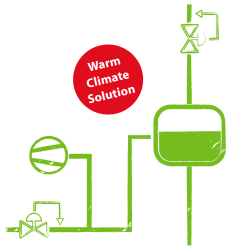
chillBooster: evaporative cooling system for CO_2 gas cooler

Especially suitable for installations in temperate climates, where the outside temperature exceeds 30 °C just a few days a year, this is a simple evaporative cooling system that can decrease the outside temperature perceived by the gas cooler by between 5 and 15 °C.
An optimum way to improve the efficiency of a transcritical system in hot temperatures, it integrates perfectly with pRack pR300T so as to ensure operation only in critical conditions or as a safety measure.



Parallel compression

The use of an additional suction line, called intermediate or parallel, improves energy efficiency and makes this type of system particularly suitable for milder climates.
The parallel compression principle is based on the possibility to exploit a more advantageous COP when the amount of flash gas forces the flash valve (RPRV) to remain open for a set period and above a certain percentage. Higher efficiency is obtained due to the lower ratio between suction and discharge pressure by using the compressors in the intermediate line rather than the compressors in the medium temperature line.
A bypass ensures the refrigerant is no longer expanded before being delivered to the medium temperature compressor suction port, but rather directly to the suction port of the compressors in the parallel line. Synchronised management of the bypass valve and parallel compression therefore increase system efficiency when the system is operating in transcritical conditions, drastically diminishing the amount of bypassed gas on the suction side and guaranteeing perfect receiver pressure control.



Ejectors, fourth-generation CO_2 systems

As an alternative to or in parallel with auxiliary compression techniques, new solutions are being investigated to increase the energy efficiency of carbon dioxide systems using static mechanical devices called ejectors.

Ejectors exploit the Venturi effect and use a primary fluid flow - typically the high pressure gas cooler outlet - which is then accelerated by choking, to draw in, mix and carry a secondary fluid at lower pressure to the suction side or liquid receiver.

The use of ejectors reduces the compression ratio and the flow-rate handled by the compressor, guaranteeing energy savings.

Transcritical CO_2, condensing

In transcritical condensing systems, CO_2 gives up heat at a temperature above critical temperature. A single stage system is where the CO_2 cooled by the gas cooler is first expanded through the high pressure valve, and subsequently, once in the liquid state, through the electronic expansion valve (before the CO_2 evaporates in the individual cabinets).

For small applications, CAREL can offer a complete and integrated solution using E2V*CS stepper valves, suitable for these types of units and featuring much simpler assembly than the larger solutions available on the market.
Carel E2V*CS CO_2 valves have maximum operating pressure 140 barg and 90 bar differential, and can be used in these types of applications with capacities up to 40 kW.
This compact solution comprises a single controller fitted with built-in driver and ultracap for direct management of E2V*CS valves used as HPVs and RPRVs. The scalability of the pRack platform allows the same user interface to be used for these types of applications, with special focus on installation costs and simple operation.

Advantages and critical situations

- system that completely uses natural refrigerants (CO_2);
- various studies have shown higher efficiency than any other type of installation (traditional R404a or subcritical CO_2) at average outside temperatures less than 15°C;
- technology becoming standardised, costs are falling.

- high pressures involved (up to 120 barg);
- systems are normally more complex than traditional ones;
- good efficiency even in warm climates (>15 °C), using additional technology such as parallel compressors, chillBooster and heat recovery

CAREL solution

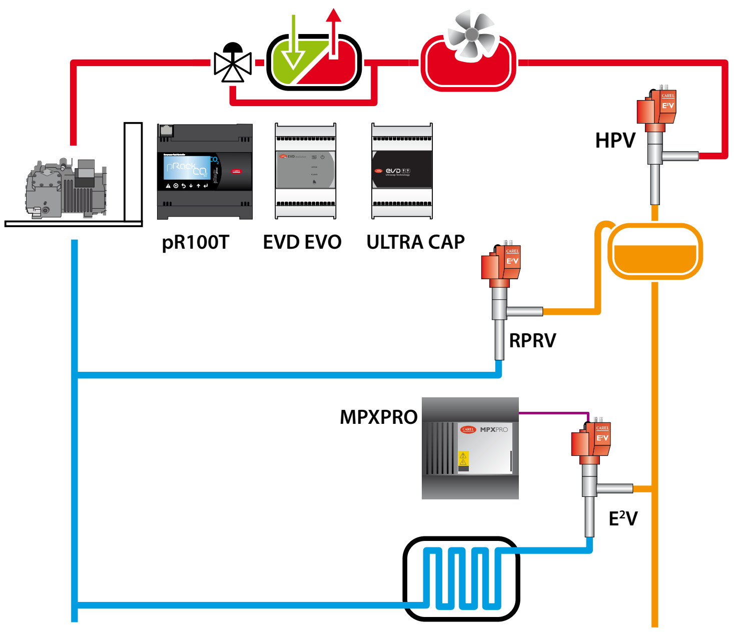
List of controllers:

- pRack pR100T for compressor racks
- E2V-C for high pressure valves
- MPXPRO + E2V for showcases
- EVDEVo + Ultracap for valve safety

pRack pR100T: controller for managing CO_2 condensing units

pRack pR100T is a compact yet powerful controller. It in fact allows complete management of small CO_2 systems from a simple and intuitive user interface, and is the ideal controller for condensing units and convenience stores.
CAREL's experience in the field of CO_2 and the increasing number of green supermarkets using the pR300T have led to the development of a powerful controller featuring high reliability and high energy efficiency for smaller units.

Control diagram with one pRack board and built-in twin driver



pRack pR300T connections

symbol	description	probe type
T_{ext}	Outside temperature	NTC - HP
P_{GC}	Gas cooler pressure	4-20 mA 0-150 barg
T_{GC}	Gas cooler outlet temperature	NTC - HF
T_{HR}	Heat reclaim temperature	NTC – HF (For heat recovery system control (optional))
P_{REC}	Receiver pressure	4-20 mA 0-60 barg
$P_{S\,L1}$	Line 1 (medium temperature) suction pressure	4-20 mA 0-44.8 barg
$T_{S\,L1}$	Line 1 (medium temperature) suction temperature	NTC – HF (For suction superheat control (optional))
$T_{D\,L2}$	Line 2 (low temperature) discharge temperature	NTC – HF (For discharge temperature control (optional))
$P_{S\,L2}$	Line 2 (low temperature) suction pressure	4-20 mA 0-44.8 barg
$T_{S\,L2}$	Line 2 (low temperature) suction temperature	NTC – HF (For suction superheat control (optional))

Common components

In addition to the solutions already described, CAREL Retail sistema offers a series of other products that are essential for system management.

PVPRO: supervisory system

Single point of access to the entire system, this allows fine tuning, continuous monitoring and logging of data, communication with the outside and alarm management.
Remote or local access with various functions to optimise system operation and increase safety:

- Floating suction pressure: optimises the compressor rack suction pressure set point based on actual system requirements;
- Dew point broadcast: to modulate showcase anti-sweat heaters using the dew point reading inside the store;
- Parameter control: to monitor vital system operating parameters, even offline, preventing accidental modifications;
- Energy: to monitor system energy consumption, create scheduled reports clearly showing system performance;
- KPI (Key performance indicators): for a quick and effective overview of the operation of the different units and clearly establish where action needs to be taken;
- Recovery procedure: together with the compressor rack, to interact directly with all the unit controllers in the event of rack malfunctions and schedule restart to get the system up and running again.

DPWL: gas leak sensors

Available for all types of refrigerant, the CO_2 leak sensor in particularis very important for installations both in equipment rooms and inside the store itself. Directly interfaceable with the electronic controllers via analogue signals or the supervisory system via Modbus RTU, these constantly monitor the level of CO_2 in the room and quickly identify any gas leaks that may be harmful to humans.
CO_2 is in fact heavier than air and can cause asphyxiation, in the event of leaks it tends to accumulate at floor level, therefore the sensors should be installed around 30-40 cm from the floor and near the refrigeration units.

VFD: inverters

Available for both compressors and fans, the CAREL VFD range of inverters covers all applications, including CO_2, and together with the pRack range allows finer control of evaporation pressure.

pChrono: scheduler

Device for scheduling the activation of lights, pumps and any other devices inside the installation, so as to maximise energy savings not only in the refrigeration system, but also the air-conditioning and building management systems.

Probes and transducers

Vast range of temperature probes and pressure transducers, available in various types, completely covering all applications with natural refrigerants:

- 4-20 mA pressure probes: recommended on compressor racks;
- Ratiometric pressure probes: recommended on showcases and in cold rooms;
- NTC and pT1000 temperature probes;
- NTC and pT1000 clamp-on temperature probes: recommended for installation on pipes.

pLoads: load control

Device for controlling loads based on system energy consumption, this activates and/or deactivates the different loads only when possible. Integrated into pRack pR300, it reduces compressor rack cooling capacity when necessary.

EXV lab

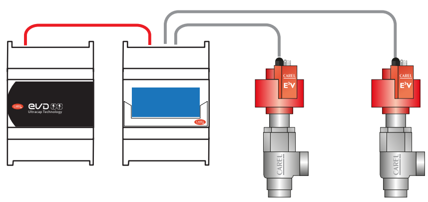
CAREL exv lab is the tool that helps users select and use CAREL valves. It is a web environment where both expert designers and novice users can find tools to select the right valve for their application, and identify the possible operating range of the EXV.

https://exvselectiontool.carel.com/ExVLab/

exv lab
the right choice

ULTRACAP for EVDEVO

Ultracap is the new emergency power supply device for electronic expansion valves, the perfect accompaniment to EVDEvo in both the single and Twin versions. The device ensures complete closing of the valves in the event of sudden mains power failures.
Exploiting ELDC (Electric Double Layer Capacitor) technology, Ultracap can supply immediate, reliable and clean emergency energy, representing a major step forwards compared to conventional battery-based systems, including as regards disposal of used materials during routine maintenance.
Ultracap means immediate energy: just four minutes after power is restored, the system is already recharged and active (in practice, the time it takes the compressor to restart…).
The extreme reliability of Ultracap, combined with the exceptional tightness of Carel valves, eliminates the need for solenoid valves even in the most critical applications.

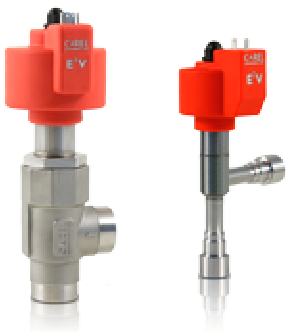


MPXPRO & E2V: controller for multiplexed showcases and stepper electronic expansion valve.

Given the speed of CO_2 as a refrigerant, evaporator control is essential for correct system operation. For this purpose, the CAREL E2V stepper electronic expansion valve is important to ensure system stability. Featuring ultracap technology, the MPXPRO + E2V system can guarantee complete closing in the system without using additional solenoid valves.

E3V-C family

The EXV-C family valves offer maximum freedom of application, managing maximum opeating pressure (MOP) up to 140 barg and able to ensure the renowned CAREL tight closure even at very high pressure differentials.
The extremely contact dimensions, part of a patented design, mean the EXV-C can be installed in any system, including existing ones (retrofit). Very high mechanical precision, reliability guaranteed by extreme lifetime testing, and maximum application versatility are the main features of the incredibly high performance that EXV-C can bring to every CO_2 circuit.



E2V family

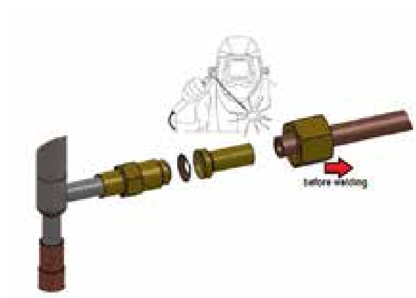
The E2V electronic valves are designed for installation in refrigerant circuits as a refrigerant expansion device, operating based on the superheat calculated by a pressure probe and a temperature probe installed at the evaporator outlet.

E2V-BSF/M

E2V-BS valves have welded fittings, and are not supplied with a mechanical filter upstream of the refrigerant inlet; nonetheless, an optional metal mesh filter can be fitted on the inlet connection, secured in place by the circuit piping, before welding the valve
CE approval: 60 bars (870psi). UL approval: 45 bars (652 psi)

E2V-BZ

E2V-BZ valves have mixed fittings and require both operations (welding and compression fittings)
The mechanical filter is supplied as standard, and in this case too, the filter features one-way flow.
CE approval: 60 bars (870psi). UL approval: 45 bars (652 psi)



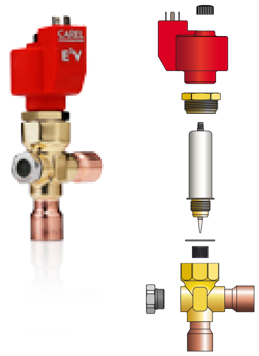
E2V-CS

As well as the traditional function of refrigerant expansion based on superheat, this valve can also be used as a pressure regulator in transcritical circuits with CO_2 refrigerant (R744)
E2V-C valves have welded fittings, and a mechanical filter always needs to be installed upstream of the refrigerant inlet.
The filter is optional or directly available in the series E2V-CS100
Main features of these valves are:

- Maximum operating pressure (MOP) up to 140 bars (2030 psi)
- Maximum operating pressure differential (MOPD) 120 bars (1740 psi) - for E2V24C**** 85 bars (1233psi))

E2V-S

E2V-S valves are welded to the circuit by brazing the copper fittings to the condenser outlet (IN) and evaporator Inlet (OUT) piping.
E2V SMART is made using modular components to be assembled during installation, guaranteeing versatility thanks to the removable cartridge.
This solution simplifies maintenance and inspection of the individual parts.
CE approval: 60 bars (870psi). UL approval: 45 bars (652 psi).



manual actuator for EXV valves

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