CO_2 Mission Critical Cooling

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TROX® AITCS

Advanced IT Cooling Systems

As written and presented by
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CO_2 Mission Critical Cooling

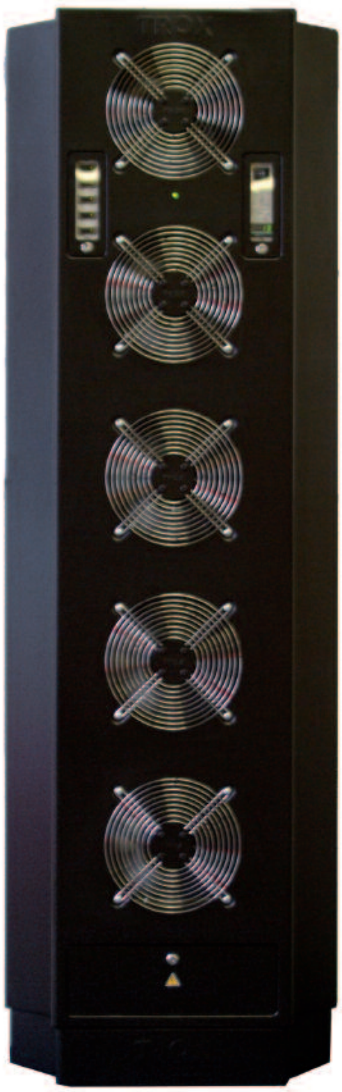
1.0 Summary

The purpose of this paper is to highlight the benefits of using liquid carbon dioxide as a secondary volatile cooling medium (Patent 2258298) within a state-of-the-art cooling system for Mission Critical environments. Mission Critical facilities provide the IT backbone in numerous sectors, including Banking, Finance, Healthcare and Military and require their cooling support systems to be of the highest standard in terms of resilience and redundancy.

Cutting edge developments in IT, as typified by Blade Servers, have seen a quantum progression in the field of microprocessor design. The hardware manufacturer's ability to develop and innovate must cascade down and be mirrored by their cooling infrastructure to ensure that their optimum operating environment is maintained.

The collaboration between Trox and its leading refrigeration partner in the areas of R&D, manufacturing and installation/project management will ensure that the system provides unprecedented future-proof cooling for ICT.

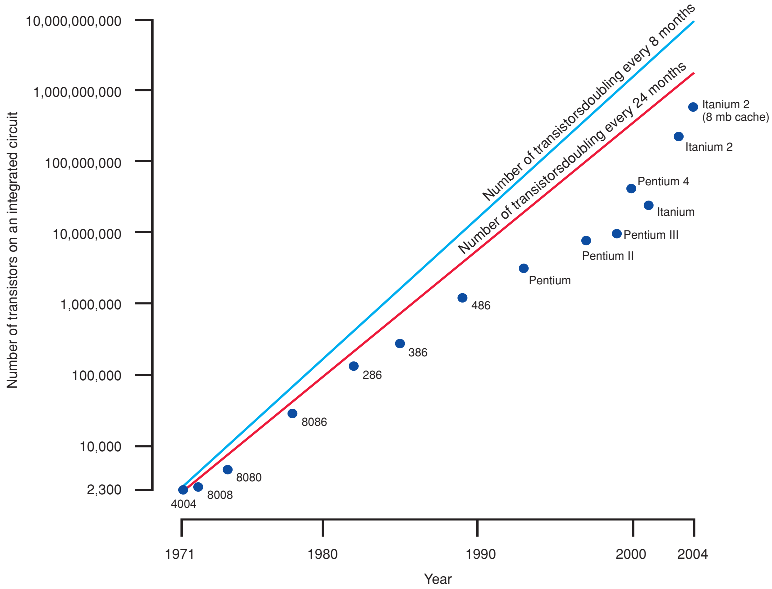
The system is offered as an integrated 'turn-key' solution, in partnership with the Client and his Design Team to:



- Satisfy high equipment loads up to 30kW per cabinet
- Achieve cabinet compaction up to 50% space saving
- Utilise electrically benign carbon dioxide: 'risk free' to IT hardware and cabling
- Design, manufacture, install, commission and service
- Prefabricate a packaged plant system with:
  - Reduced installation time on site
  - Consistent quality through specialist skilled labour
  - Optimum energy efficiency up to 30% saving
- Satisfy resilience and redundancy requirements up to a Tier IV (N+N) rating:
  - Run standby service items
  - Dual delivery pathway
  - Leak detection and isolation

2.0 Rising I.T. loads

The ever increasing demands of Information Communication Technology (ICT) are closely plotting Moore's Law and his predictions for advances in processing power.



- Graph plotting Moore's Law

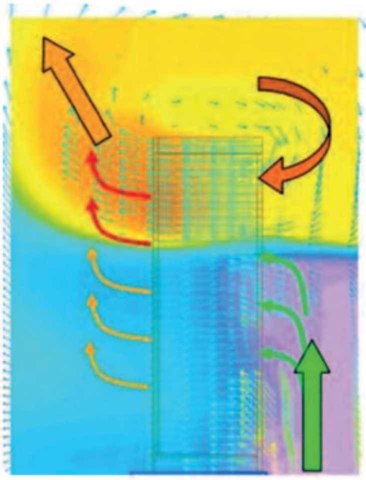
2.1 Blade Servers

The advancements in high capacity computer equipment are typified by blade servers. The use of leading edge hardware demands a resilient high capacity cooling solution. It is a pre-requisite that science and innovation must combine as cabinet loads in excess of 20kW become the norm. The longevity of a cooling solution may only be guaranteed where it is likely to provide future-proofing for loads in excess of 30kW per cabinet. Blade Server heat loads are dramatically higher than those previously seen. The heat load is dependant on their power supply, currently topping-out at around 24kW for an 800mm wide x 47U cabinet; equating to a huge 14kW per/m2 for the net cabinet and aisle area. These loads can be compared to those seen in the last few years of around 1 or 2kW per cabinet.

3.0 Conventional Cooling Solutions

Are widely recognised to be at their practicable limits and unable to deal with the intensive heat load that this technology demands. The ideal of fully loaded 'blade' cabinets may not be realised with existing cooling solutions.

3.1 Air



Courtesy of J. Pappas Mazzetti & Associates

Short circitting from the hot aisle at the back of the cabinet into the cold aisle.

Has long been the staple of cooling technicians, but is impractical when these exceptional heat loads necessitate hourly air change rates of 1000+. The task of supplying sufficient cooling from the CRAC (computer room air conditioning) units into the floor void is relatively straight forward; however, achieving even air distribution across the floor and then through the technical space is extremely difficult if not impossible. It is imperative that an even air plume is achieved across the face of the cabinet to enable the server fans to draw their required air volume. Airflow management necessitates careful planning to avoid short circuiting from the hot to the cold aisle. Poor airflow and air re-circulation may result in the servers at the top of each rack overheating. The maximum practical limit for air cooling is considered to be 5 to 8 kW per cabinet, but is dependant upon cabinet layout, space constraints and airflow strategy.

"The failure rate at the top third of the rack is three times greater than at the bottom." *Mr. Kenneth Brill, Executive Director: The Uptime Institute, March 2003 DataCenter Dynamics Conference)*

3.2 Water

Offers a more efficient means of cooling the cabinets over air. The Trox patented COOLrac with its heat exchanger mounted directly on the discharge of the cabinet can achieve up to 10/12kW, and demonstrates the benefits of heat absorption. Short circuiting from hot to cold aisles is therefore eliminated. However, water as a conductor of electricity often deters the I.T. world from utilising cooling solutions that impose a water-electronics mix that presents an unacceptable risk to business. In the extreme, un-quantifiable financial down-time losses could result from damage to the servers or Cat 5 cabling. In a risk-averse environment, a void warranty will necessitate a controlled hardware replacement.

It was the pursuit of 'damage' and 'risk' limitation that continued to drive the development of COOLrac. With the beneficial characteristics of 'heat absorption' being well documented, the next challenge became the utilisation of an electrically benign cooling medium.

4.0 Carbon Dioxide Cooling

Carbon dioxide is the perfect cooling medium as it offers a solution to the many challenges associated with cooling in the ICT environment. The key properties of carbon dioxide include:

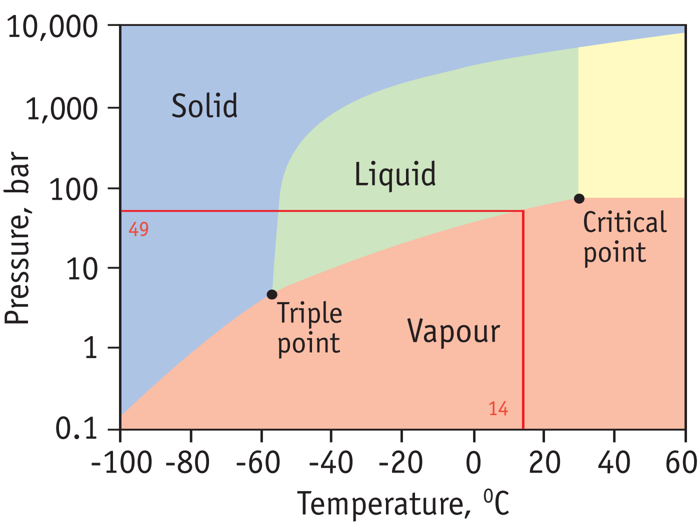
- Electrically benign, non-hazardous to servers or cabling.
- Increased cooling capacity: seven times over water; allows much reduced volume flows and smaller diameter distribution pipework.
- Reduced viscosity and volume flows, lessens the consumption of pumping power, with up to a 30% energy saving (see energy comparison, section 4.3).
- The heat is absorbed during a 'phase-change' process with no rise in temperature.

The latent heat capacity Carbon Dioxide is 182kJ/kg compared to the specific heat capacity of H_2O = 4.2kJ/kgK, which means that:

- 1kg of CO_2 can absorb 182kJ of energy in is 'phase change' from liquid to gas
- 1kg of H_2O can absorb 4.2kJ of energy for each degree in temperature rise
  - with CHW flow/return of 6/12°C, 1kg of H_2O can absorb 25.2kJ
- Therefore 1kg of CO_2 can absorb over 7 times more energy than water
  - 182kJ / 25.2kJ = 7.22kJ

4.1 Volatile Substance

The liquid carbon dioxide is circulated through the secondary cooling system only. Primary cooling and heat rejection to atmosphere is either via an air cooled or water cooled chiller, or by utilising the building's existing chilled water system. The diagram below shows the three 'Pressure-Temperature' phases of CO_2 namely solid, liquid and vapour. The triple point sets the lower temperature limit (-56.6°C) for the heat transfer process based upon evaporation and condensation, where the CO_2 co-exists as all of its 3 phases. CO_2 cannot be liquefied above the critical point (31°C) which is the upper limit for its use as a volatile heat transfer fluid. The CO_2 system is charged to a pressure of 49 bar (A), which holds the CO_2 at a temperature of 14°C and above room dew point to avoid condensation. The CO_2 is maintained at 14°C by control of the primary cooling medium.



4.2 The Green Gas

Carbon dioxide is a low cost natural gas. Its ample supply is derived as a waste by-product from industrial processes and therefore, in this application, can be considered as having a negative Global Warming Potential. The reduced power consumption of the system will result in CO_2 emissions which include the supply of the specialist capital plant.

CO_2 has been selected as the secondary coolant for the system owing to its 'electrically benign' status over water and because CO_2 is least harmful of all those that have a Global Warming Potential (GWP).

The table below plots the GWP of carbon dioxide against other refrigerants:

GWP Table												
Refrigerant		Physical Data				Safety Data				Environmental Data		
No.	Formula	Molecular Mass	NBP (°C)	Critical Point (°C)	Critical Point (MPa)	TLV- TWA (ppm)	LFL (%)	HoC (Mj/kg)	ASHRAE Safety Group	Atm. Life (yr.)	ODP	GWP (100yr)
134a	CH2FCF3	102.03	-26.01	101.1	4.06	1000		4.2	A1	13.6	0	1600
404A	R- 25/143a/134a (44/52/4 %)	97.6	-46.6	72.1	3.74	1000		-6.6	A1/A1		0	4540
407C	R-32/125/134a (23/25/52 %)	86.2	-43.8	87.3	4.63	1000		-4.9	A1/A1		0	1980
R22	CHCl F2	86.47	-40.8	96.15	4.99	N/A	N/A	2.2	A1	11.8	1.034	1900
Ammonia	NH3	17	-33.3	132	11.34	25	16	22.5	B2	0	0	0

Where:

NBP - normal boiling point; i.e. the boiling temperature at atmospheric pressure (101.33kPa)

TLV-TWA - threshold limit value-time-weighted average; as referenced in ASHRAE Standard 34-1997

LFL - lower flammability limit; as defined in ASHRAE Standard 34-1977

HoC - heat of combustion; as defined in ASHRAE Standard 43-1977

ODP - ozone depletion potential

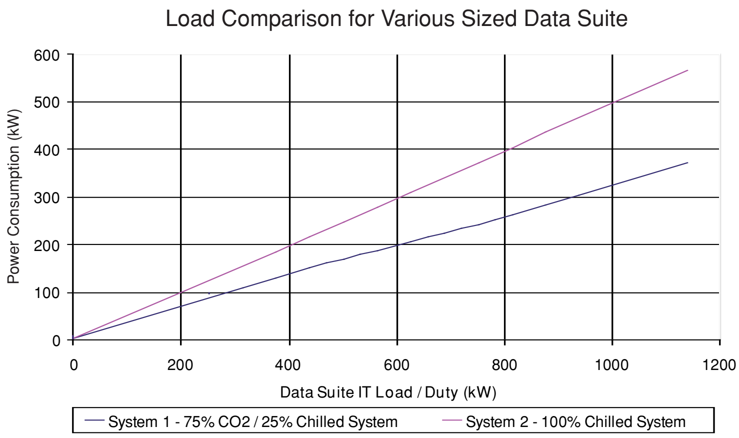
GWP - global warming potential; 100 year integration

4.3 Low Energy & Reduced Carbon Emissions

The system increases cabinet cooling capacities and may be specified to provide a reduction of consumed energy in the provision of cooling. Where maximum energy savings are required the air cooled or water cooled chiller may be specified. A desk top study, conducted by consultant hurleypalmerflatt (HPF), established the savings in motive power to provide cooling from a scheme utilizing the air cooled chiller and secondary CO_2 system over 'air-water' cooling solutions. The analysis compared a conventional chilled water system using Computer Room Air Conditioning (CRAC) units that deliver air into the floor void, against a system that had 75% of its cooling via the CO_2 system and 25% via CRAC units. The hybrid system uses the CRAC units to provide cooling to the 'low' load cabinets and humidity control through its CHW flow/return temperatures of 6/12^{o}C.

CO2 System Summary		Combined CO2 and Chilled Water System Summary	
System Duty/ Size	Power Consumption per kW Cooling	System Duty/ Size	Power Consumption per kW Cooling
150kW	0.323	200kW	0.372
260kW	0.292	350kW	0.351
360kW	0.268	480kW	0.322
720kW	0.268	n/a	n/a
1080kW	0.268	n/a	n/a

Coefficient of Performance data for the CO_2 and CHW cooling system (courtesy of HPF)



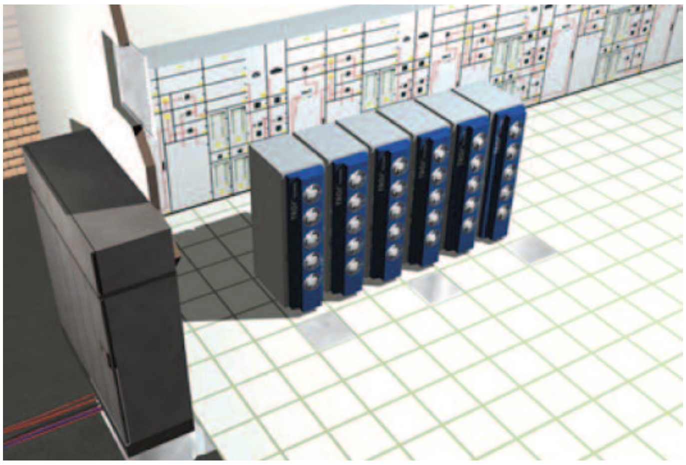
Power Consumption data for the CO_2 and CHW cooling system (courtesy of HPF)

4.4 Cabinet Compaction

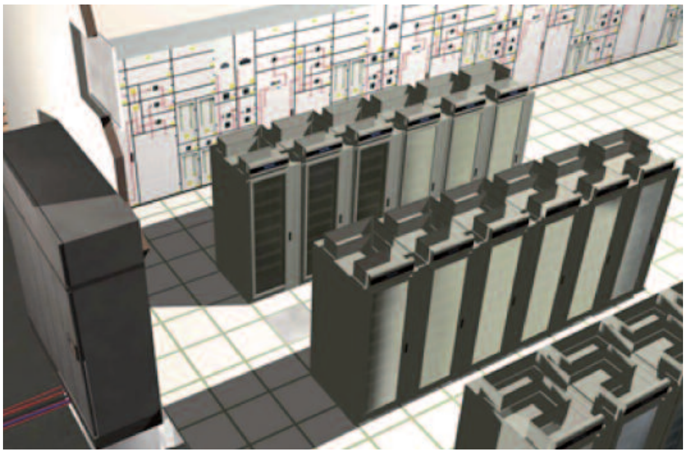
Is achieved through high capacity CO_2 cooling: a 'technical refresh' can deliver net savings on floor area of up to 70% over air systems. High capacity, up to 30kW per cabinet, offers future-proofing and flexibility to exceed market expectations. The opportunities for reclamation of space in SER's, MER's and CER's will prove the business case for CO_2 cooling. The following table illustrates the minimum floor area requirements and potential space saving of high compaction CO_2 cabinets versus cabinet mounted water cooling, and conventional air cooling via CRAC units.

System	Cooling per Cabinet (max)	Data Center Load			
		200kW	1000kW	2000kW	5000kW
CO_2	30kW	37m^2	117 m^2	214 m^2	534 m^2
Cabinet H_2O	15kW	73 m^2	233 m^2	427 m^2	1067 m^2
CRAC	8.0kW	129 m^2	412 m^2	753 m^2	1882 m^2

150kW CO_2OLrac installation
Maximum cabinet compaction minimises rack space.

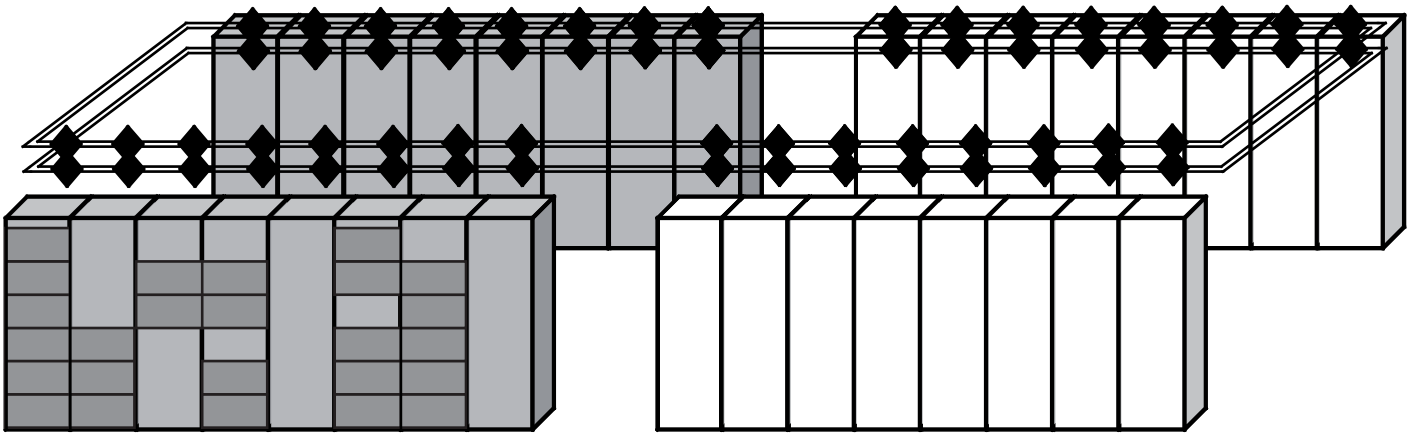


150kW CRAC installation
Server dissipation necessitates additional cabinets



4.5 Server Flexibility – Load Diversity

With cabinet cooling capacities now available up to 30kW, innovative deployment of a flexible 'plug and play' CO_2 distribution network can facilitate an architectural IT upgrade that will compliment ICTs unpredictable challenges of cabinet and server relocation. Deployment of a 'future capacity' CO_2 ring main with additional manifold connection points provides total freedom for heat load diversity among the high capacity cabinets. The same strategy may be used to provide the infrastructure for future upgrades. High pressure CO_2 does not require the system to be re-balanced as the 'loads' are re-positioned, to provide total architectural IT freedom.



Flow and return ringmain and valve manifolds

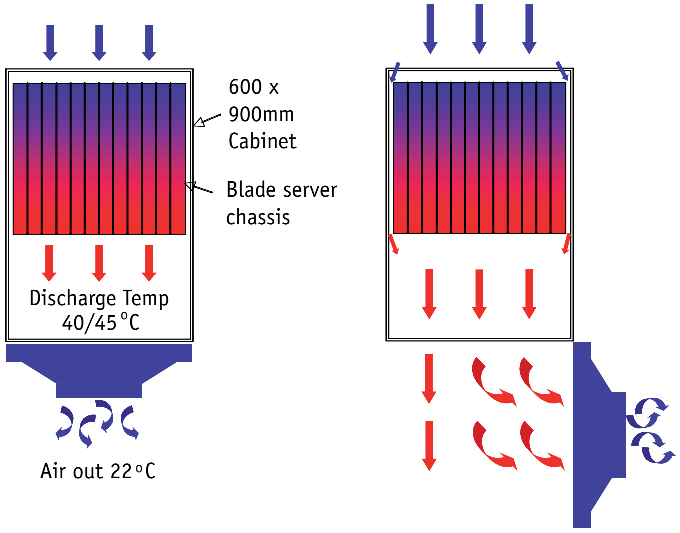
5.0 CO_2OLrac (Patent application 0421232.0)

The base design for the CO_2OLrac incorporates a rear door mounting detail. Alternative designs are available for the unit to be fitted on the side, front, top or in the base of the cabinet.
High quality flexible connections allow continual access to the server cabinets through normal operation of the door. The unit's scalloped design provides a 90° operation of the door.
The CO_2OLrac is design to:

- Geometrically scale up or down in size to achive optimum performance across the entire heat rejection area; nominal depth of the unit 250mm.
- Achive a good mounting interface between the cabinet rear door (by others) and the cooler.
- Casters transfer the weight of the cooling unit (85kg) to the floor.

5.1 Heat Absorption

The design philosophy of the CO_2OLrac is to absorb the heat at the rear of the cabinet as it is rejected by the servers. It is acknowledged that the most effective means of cooling is to deal with the load as close to the source as possible. The server loads, once absorbed, are neutral to the technical space. With the door fully open, approximately 60 to 70% of the rejected heat from the cabinet servers will be drawn through the CO_2OLrac's heat exchanger, and thus absorbed. Around 30 to 40% of the equipment heat will spill out into the aisle, thus raising the local ambient temperature by around 1 to 2°C. The holistic redundancy offered by the system will ensure that the increased load within the aisle will be absorbed by adjacent cabinets



5.2 Performance Table

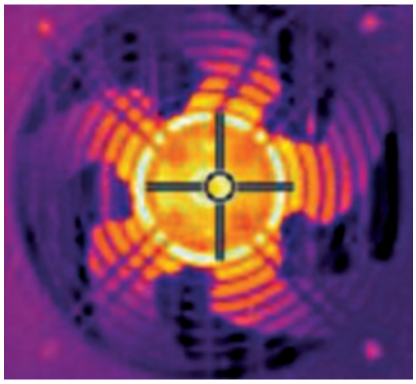
Width x Height	Air vol l/s (max)	Air on oC	Air off oC	kW
600mm x 42U	655	22	47	20
800mm x 47U	983	22	47	30

- 1U, equals 1.75", is the standard measuring unit of height for equipment cabinets

5.3 Optimum Coil Performance

The system design is based on circulating CO_2 at a temperature of 14°C. The CO_2 absorbs the heat across the coil and 'boils off' to a liquid with the vapour held in suspension. The greater the load the greater will be the concentration of vapour within the CO_2. The system has a 50% overfeed of CO_2 so that the heat exchanger's internal surfaces are always 'wet'. This design feature ensures that the vigorous latent heat exchange process e.g. 'phase change' may always occur; all the while a differential in temperature, e.g. 'a load', is present across the coil. The CO_2 overfeed provides a further benefit of achieving an increased capacity on any individual unit which may be necessary if an adjacent CO_2OLrac is out of service, e.g. a 20kW unit is able to compensate up to a load of 25kW due to the system's CO_2 overfeed.

5.4 Variable Speed Fans - Optimised Airflow



The unit is fitted with five fans on an N+1 basis. The fans create a negative pressure within the rear of the cabinet. The unit has been designed with the imperative that the CO_2OLrac does not compromise the airflow characteristics of the server's fans.
The unit's airflow will always operate at a slightly greater air volume than that of the server. Creation of a negative pressure regime between the cabinet and cooler along with careful airflow management ensures that short circuiting (rear to front) within the cabinet itself is avoided.
The fans may be selected to suit power supplies of either 230V or 115V. Beneath a lockable access panel, each fan has its own fused power isolation switch (to enable a fan 'hot swap' in the event of fan failure) and a 3-speed controller. Four quick relase fixings (accessible roomside) and plug and socket connections provide a rapid change over. The fan speed is set based on running all five fans at 125% volume of the cabinet total. In failure mode of a single fan, the unit's duty will operate at 100% airflow. To provide resilience to the system it is recommended that the fans should be backed up on the buildings' Uninterruptable Power Supply (UPS), each fan draws 150W (max).

5.5 Temperature Display

The unit incorporates a digital temperature display to provide facilities management with a visual and BMS indication of the local off-coil temperature for each cabinet. The off-coil temperature will provide an early confirmation that the units are operating succesfully. Excessive off-unit temperatures above room design condition could indicate insufficent heat absorption.

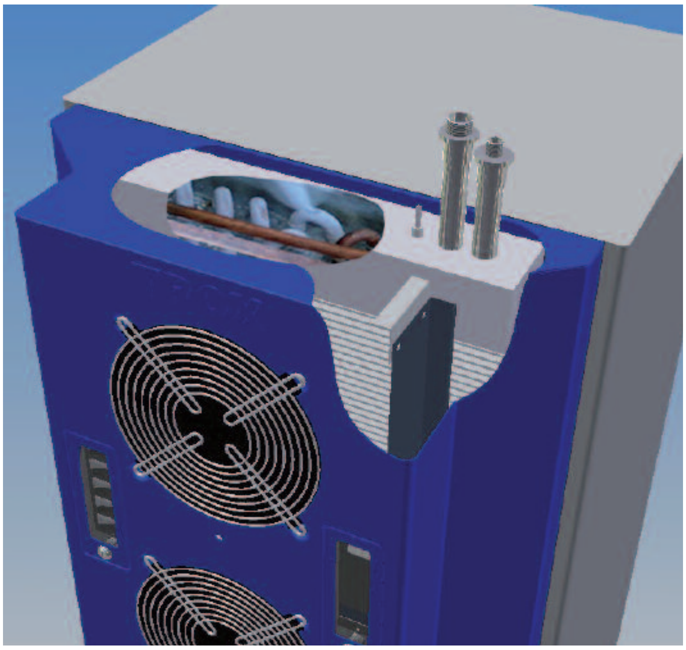
5.6 LED Alarm Indicator

A dual purpose LED indicator is fitted to the front of each cabinet. The purpose of the indicator is to provide a rapid means of locating a cabinet that requires maintenance, either in the form of a fan replacement or due to the automatic isolation of CO_2 to the unit. Failure indication, for each scenario, will also alarm at the BMS.

5.7 Coil Integrity

Is continually monitored through the CO_2 leak detection system (patent 0515399.4 pending). Automatic shut-off valves will provide instant isolation of the CO_2 supply to a cabinet that has a failed coil.

In the unlikely event of a coil failure, the cabinet continues to reject its heat, thereby raising the local ambient temperature by around 1 to 2°C. The servers will continue to operate within their safe working limit up to the point of a number of simultaneous coil failures from adjacent cabinets.



- example detection chamber surrounding coil bends, with destructive burst test at 290bar(A)

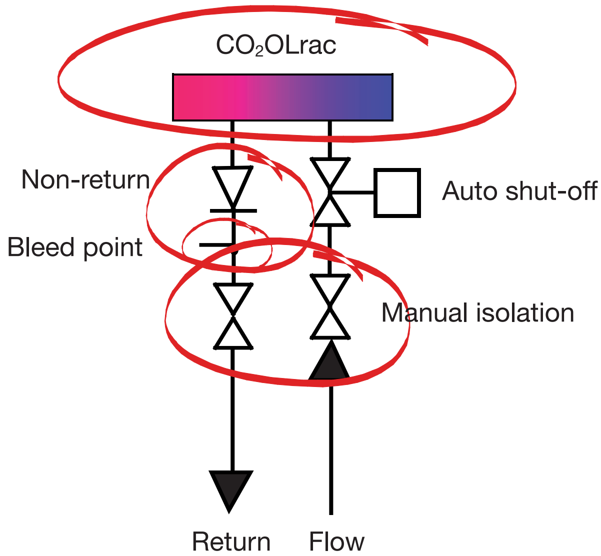
Where redundancy levels up to an N+N standard are required, this may be catered for with the inclusion of a second heat exchanger.
High integrity coils of high grade copper have been specified to minimise the risk of leaks. Destructive testing of coils, which are designed for working pressures of 49bar (A), have remained intact for pressures in excess of 200bar (A)!
The patented leak detection system has been designed to provide immediate isolation of the heat exchanger in the event of a failure. The concentration of CO_2 falls to a safe limit through the rapid mixing achieved by the integral fans, and it dissipates to gas.
The design allows a combination of detection methods to be specified that include:

- CO_2 concentration levels within each CO_2OLrac are monitored at the bottom and top of the unit within a purpose designed detection chamber that encloses the heat exchanger's U-bends.
- The detection chamber's pressure level is monitored and will provide an immeadiate indication of a gas escape and increase in pressure.
- Local temperature monitoring within the detection chamber to provide a third method of alarm; a release of CO_2 will cause a reduction in chamber temperature.

5.8 Cabinet replacement

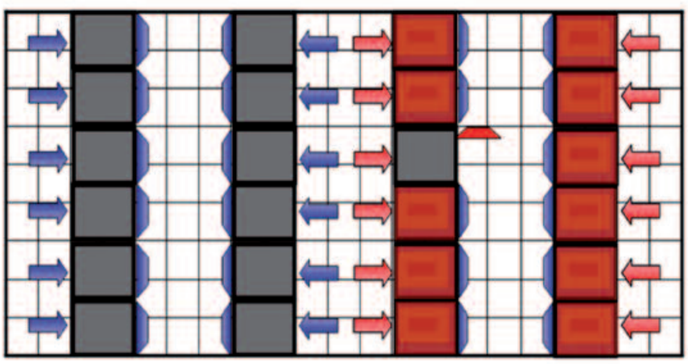
The replacement of each CO_2OLrac has been designed to be simple, performed as part of a service level agreement. For expediency a spare CO_2OLrac is stored on site and should contain a hydrated coil, sealed; the complete unit shrink-wrapped and protected.
Rapid replacement of the CO_2OLrac:

- Isolate CO_2OLrac cooler
  - Manual control valves
  - Flow and return
- Release cabinet CO_2 charge
  - Via bleed point
- Remove existing CO_2OLrac
- Supply/fit new CO_2OLrac
- Extract air from CO_2OLrac
  - Vac pump via bleed point
  - Utilise non-return valve
- Open manual control valves
- Refill cabinet CO_2 charge



5.9 Holistic Resilience

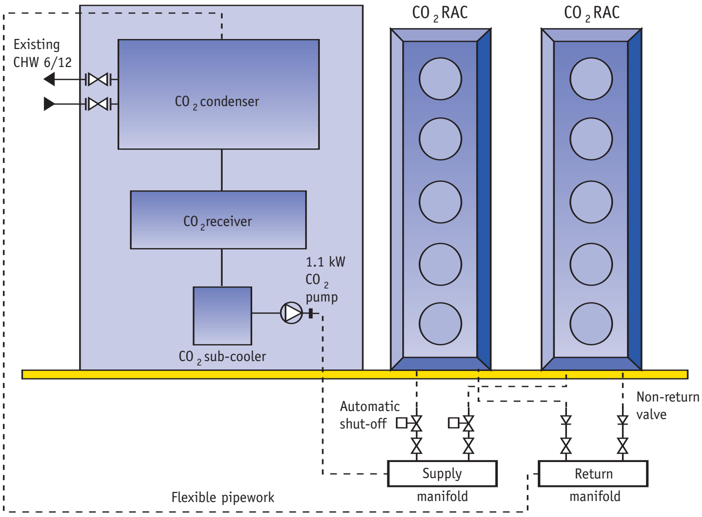
Is achieved as each CO_2OLrac is served from a central supply of CO_2. If an individual CO_2OLrac 'is out of service the servers will continue to operate and reject their load into the aisle, thereby raising the local ambient temperature. This additional heat load will increase the temperature differential across the heat exchangers within surrounding CO_2OLracs increasing the latent heat exchange, and therefore providing a self compensating system.
The system design includes for the provision of overfeed of CO_2 that boosts the effective capacity of each unit thus providing enhanced system resilience (see section 5.3).



- Surrounding cabinets compensate for an isolated cabinet. In the event of multiple fan failure the cabinet door is opened.

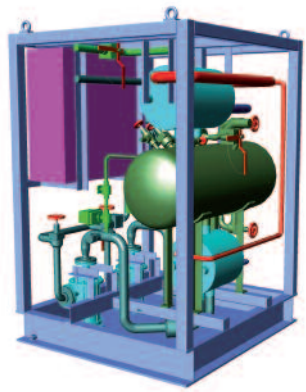
6.0 Alternative Primary Cooling Systems

Three system designs provide the Client with the flexibility to deploy the CO_2 cooling solution that best suits his new-build or existing cooling platform.



Patent 2258298

6.1 CO_2OLpac



Is designed for existing buildings that have sufficient chilled water to meet the cooling demands, but whose client has a desire for high capacity cabinet cooling without water in the technical space. The solution introduces an interface between the chilled water with the secondary carbon dioxide circuit, via a plate and shell heat exchanger. The CO_2 is pumped around the ringmain and serves each rack in a parallel circuit. The existing chilled water supply (typically operating at flow and return temperatures of 6/12°C) and 3-way valve is controlled to maintain the circulating CO_2 at a temperature of 14°C.

The self contained 'CO_2OLpac' is suitable for indoor or outdoor location, and houses the high integrity 'plate and shell' heat exchanger, receiver vessel and circulating pumps. It has been designed to be compact enough to enable its location to be immediately adjacent to the main/central equipment room (MER or CER) or the 'on-floor' satellite equipment rooms (SER). The integral sub-cooler ensures that the optimum head pressure is achieved across the pump even with its low height construction.

CO_2OLpac Technical Data:

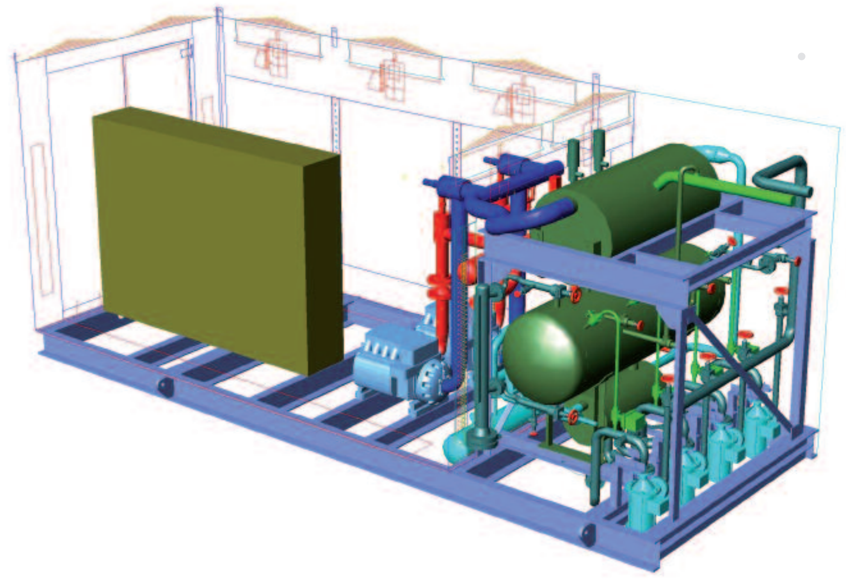
	Model	CPC80	CPC200	CPC300
GENERAL	Nominal Capacity (kW)	80	200	300
	Dry Bulb Temp. (°C)	32	35	35
	Power Supply (V/Ph/Hz)	400/3/50	400/3/50	400/3/50
	SPL (dB(A) @ 10m)	TBC	TBC	TBC
	(L x W x H) –(m)	1.4 x 1.3 x1.92	1.7 x 1.5 x 2.0	2.2 x 1.9 x 2.1
	Operating Weight (kg)	1500	2750	4000
	Coolant	Chilled water	Chilled water	Chilled water
	Starting current (A)	TBC	TBC	TBC
	CO_2 Pipes Size	32 NB	40/50 NB	65NB
CO_2 CONDENSER	Type	Plate and shell	Plate and shell	Plate and shell
	Plate Side Medium	Chilled water	Chilled water	Chilled water
	Shell Side Medium	CO_2	CO_2	CO_2
	Plate Temp In/Out (°C)	6/12	6/12	6/12
	Shell Temp In/Out (°C)	14	14	14
	Pressure Drop (kPa)	39	60	TBC
CO_2 PUMPSET	No Off	1+1	2+1	3+1
	Type	Hermetic	Hermetic	Hermetic
	Capacity (kW)	110 each	110 each	110 each
	Motor Rating (kW)	1.2 x 2	1.2 x 3	1.2 x 4

CO_2 Mission Critical Cooling

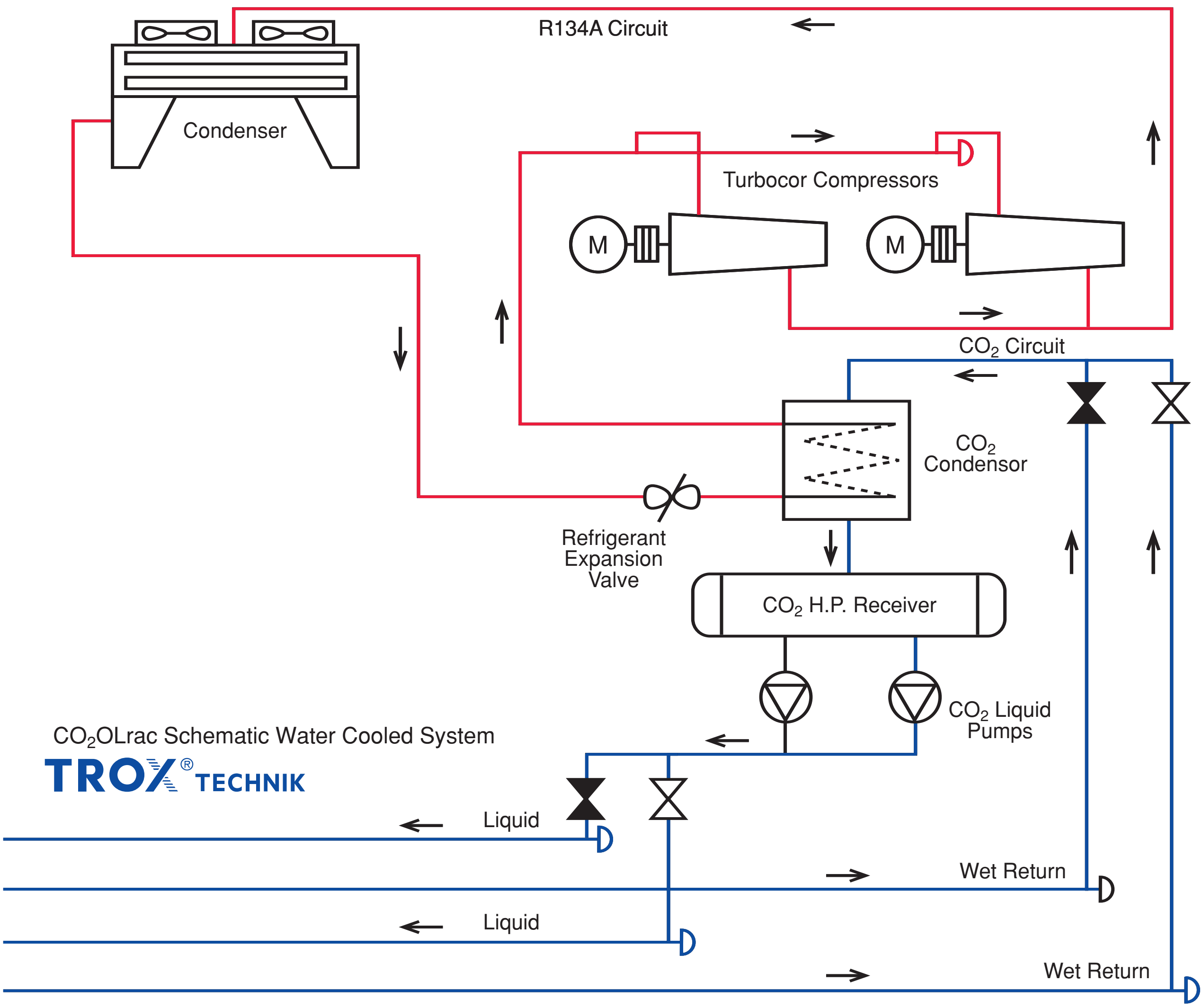
6.2 CO_2OLairpac

Is designed for outdoor applications and offers the optimum cooling solution where energy efficiency is of primary importance and an independent cooling system is preferred. The system provides the perfect combination of a low energy chiller with highly efficient carbon dioxide rack cooling.

The air cooled R134a chiller has a range of capacities from 300kW to 750kW. This low energy primary cooling plant comes complete with run and standby state-of-the-art Danfoss-Turbocor compressors. The compressor has an exceptionally low starting current of just 2amps; inverter capacity control; oil free magnetic bearings providing an energy efficient system, which benefits from quiet operating noise levels. With an ‘oil free’, ‘zero leak’ design the maintenance requirements are minimal. The packaged CO_2OLairpac houses a purpose designed integral CO_2OLpac complete with its heat exchanger, receiver vessel and circulating pumps.



- CO_2OLairpac schematic - primary cooling with R134a chiller, plate shell heat exchanger and secondary CO_2 distribution pipework which may be designed with 100% back-up.

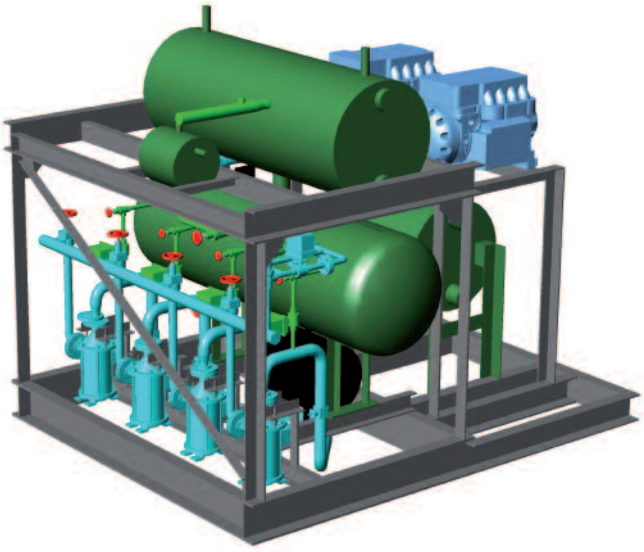


CO_2OLairpac Technical Data:

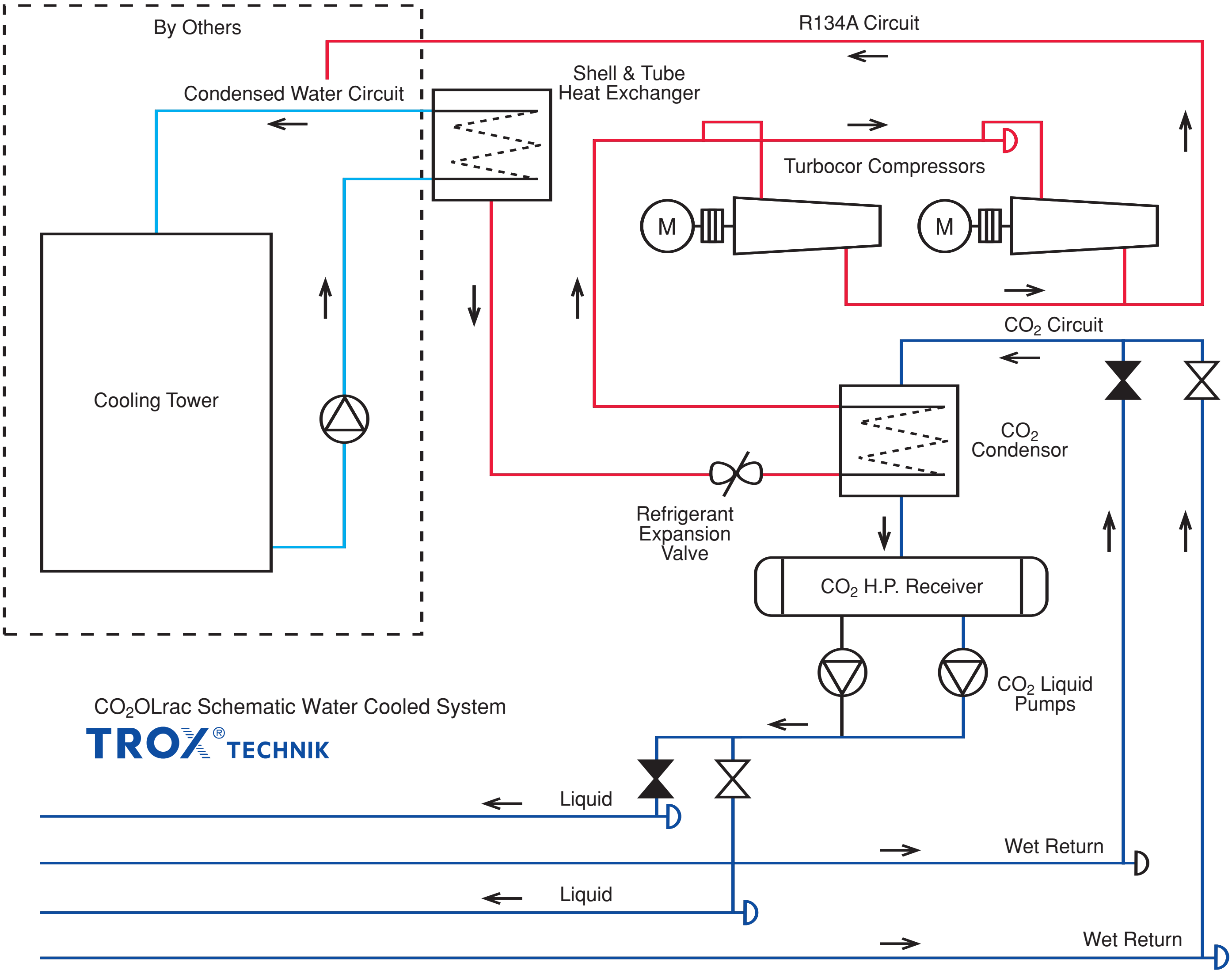
	Model	CPA300	CPA500	CPA750
GENERAL	Nominal Capacity (kW)	300	500	750
	Evaporating Temp. (°C)	9	9	9
	Condensing Temp. (°C)	50	50	50
	Dry Bulb Temp. (°C)	32	35	35
	Power Supply (V/Ph/Hz)	400/3/50	400/3/50	400/3/50
	SPL (dB(A) @ 10m)	56	57	58
	(L x W x H) - (m)	5.7 x 2.2 x 2.4	7.2 x 2.3 x 3.1	8.7 x 3.0 x 3.6
	Operating Weight (kg)	9000	11700	15300
	Refrigerant	R134a	R134a	R134a
	Starting Current (A)	126	249	373
	Full Load Current (A)	162	323	485
	CO2 Pipes Size	50/65NB	65NB	80NB
CENTRIFUGAL COMPRESSORS	Quantity	1+1	2+1	3+1
	Type	Oil free	Oil free	Oil free
	Drive	Inverter	Inverter	Inverter
	Absorbed Power (kW)	77.9 each	64.5 x 2	64.5 x3
	Enclosure	IP54	IP54	IP54
R134a CONDENSER	Type	Air cooled	Air cooled	Air cooled
	Heat Rejection Cap. (kW)	390	634	952
	Air Flow (m3/s)	30	36.8	55.2
	No. of Fans	6	8	12
	Absorbed Power (kW)	8.4	8.8	13.2
	Fan Speed (RPM)	695@50Hz	695@50Hz	695@50Hz
CO_2 CONDENSER	Type	Plate and shell	Plate and shell	Plate and shell
	Plate Side Medium	R134a	R134a	R134a
	Shell Side Medium	CO2	CO2	CO2
	Plate Temp In/Out (°C)	9/13	9/13	9/13
	Shell Temp In/Out (°C)	14	14	14
CO_2 PUMPSET	No Off	3+1	2+1	2+1
	Type	hermetic	hermetic	hermetic
	Capacity (kW)	110 each	330 each	490 each
	Motor Rating (kW)	1.1 x 3	3 x 2	5.5 x 2

6.3 CO_2OLwaterpac

Achieves the pinnacle in energy efficiency. The system utilises cooling tower water to reject the heat from the CO_2OLwaterpac low energy chiller. The water cooled R134a chiller has a range of capacities from 300kW to 900kW. This low energy primary cooling plant comes complete with run and standby Danfoss-Turbocor compressors. The packaged CO_2OLwaterpac houses a purpose designed integral CO_2OLpac complete with its heat exchanger, receiver vessel and circulating pumps.



CO_2OLwaterpack schematic -



CO_2OLrac Schematic Water Cooled System

TROX® TECHNIK

CO_2OLwaterpac technical data:

	Model	CPW300	CPW600	CPW900
GENERAL	Nominal Capacity (kW)	330	660	990
	Evaporating Temp. (°C)	9	9	9
	Condensing Temp. (°C)	40	40	40
	Dry Bulb Temp. (°C)	32	35	35
	Power Supply (V/Ph/Hz)	400/3/50	400/3/50	400/3/50
	SPL (dB(A) @ 10m)	<70	<70	<70
	(L x W x H) –(m)	2.6 x 2.1 x 2.2	2.9 x 2.3 x 3.14	2.9 x 3.0 x 3.6
	Operating Weight (kg)	5359	7580	11657
	Refrigerant	R134a	R134a	R134a
	Starting current (A)	30	57	85
	Full Load Current (A)	142	283	425
	CO_2 Pipes Size	50/65NB	65NB	80NB
CENTRIFUGAL COMPRESSORS	Quantity	1+1	2+1	3+1
	Type	Oil free	Oil free	Oil free
	Drive	Inverter	Inverter	Inverter
	Absorbed Power (kW)	63.8	63.8x2	63.8x3
	Enclosure	IP54	IP54	IP54
R134a CONDENSER	Type	Plate and shell	Plate and shell	Plate and shell
	Plate Side Medium	Water	Water	Water
	Shell Side Medium	R134a	R134a	R134a
	Plate Temp In/Out (°C)	29/35	29/35	29/35
	Shell Temp In/Out (°C)	40	40	40
	Pressure Drop (kPa)	11	17	47
CO_2 CONDENSER	Type	Plate and shell	Plate and shell	Plate and shell
	Plate Side Medium	R134a	R134a	R134a
	Shell Side Medium	CO_2	CO_2	CO_2
	Plate Temp In/Out (°C)	9/13	9/13	9/13
	Shell Temp In/Out (°C)	14	14	14
CO_2 PUMPSET	No Off	3+1	2+1	2+1
	Type	hermetic	hermetic	hermetic
	Capacity (kW)	110 each	330 each	490 each
	Motor Rating (kW)	1.1 x 3	3 x 2	5.5 x 2

7.0 Installation and Commissioning

The CO_2 cooling system is provided on a supply and install basis. Experienced and qualified engineers will design and install the complete system, tailoring it to match the end user's redundancy requirements and building constraints. Prior to hand-over the system is fully pressure tested to one-and-a-half times working pressure; an integral part of the testing phase. The commissioning process will include full load testing to ensure that the cooling capacity satisfies the demanding load environment that it has been designed for. Commissioning is accelerated through the elimination of volume flow valves which, owing to the circulating pressure of the CO_2 system, ensures that the CO_2 flow will be relatively even along the pipe runs, excepting for minimal fluctuations due to pressure losses.

7.1 Distribution Pipework

The CO_2 distribution may be via flexible pipework (convoluted stainless steel with stainless overbraid) or stainless steel rigid pipe, fully welded. Dual pipework systems are used for Tier IV (N+N) systems. The flexible pipework is laid on cable tray at either high or low level (beneath the false floor). The use of flexible pipework in the data suite offers a system that can accommodate cabinet relocation. The joints, either threaded connection or flange plates avoid hot-works (welding) which may not be permissible in a live data suite environment.

The CO_2OLrac unit is connected using high quality flexible pipework to prefabricated, pressure tested/x-rayed manifold blocks (for schematic see section 5.7). The manifolds are located at pre-determined points around the ring-main, often with future cabinet expansion in mind. The manifolds include manual & automatic isolation valves, non-return valve and bleed point.

Flow/return connections to CO_2OLrac

7.2 Maintenance, Servicing, Equipment Monitoring

A full maintenance and servicing level agreement is available to ensure that the system continues to operate effectively in this business critical environment. Support is available on a term contract and emergency call-out basis to provide 24-7-365 support.

A detailed maintenance schedule is available on a project by project basis. Water cooled systems require weekly and monthly inspections of the installation for water leaks. A 6-monthly inspection is required of the control panel, relief valves and cut-outs. The annual inspection would include checks in accordance with the Pressure Systems Safety Regulations and checking of the cut-outs and strainers. CO_2 pumps would have annual or 2-yearly inspections depending on running hours.

Remote monitoring of plant and equipment is available through the web-based Telstar system, which enables the equipment to be monitored remotely in order that a proactive approach can be taken to anticipate and eliminate cooling down-time. A range of alarms and support are available, dependant on the service level agreement, to give early warning of CO_2 space concentration levels, system pressure level; pump status; CO_2OLrac fan status and off coil temperature.

7.3 Health & Safety

Careful development of the system ensures that the volume of CO_2 in circulation is limited. As with all refrigerants large escape volumes within the occupied space, present a health hazard. To reduce any potential risks to personnel through leaks, the design incorporates gas detection and automatic isolation valves at every CO_2OLrac. Isolation valves are also deployed at predetermined locations along the distribution pipework route from the plant through and to the data space. Ramped alarm signals, dependant on concentration level, are then available for connecting to the building BMS. The 2-stage warning system CO_2 concentration values are:

- 2500 parts per million (ppm): Visual inspection of 'affected zone', which could be a single cabinet, pipe route through to the space, part of the ring main, or plant equipment.
- 5000 (ppm) Isolation of the 'affected zone': in systems with Tier IV redundancy the back-up system will ensure continual cooling.

CO_2 detection and alarm

The gas detection system will continually monitor the CO_2 concentration and the building's ventilation system would be used to disperse the CO_2 from the space in the unlikely event of a release.
The Institute of Refrigeration "Safety Code for Refrigerating Systems Utilizing Carbon Dioxide" describes the safe use of CO_2 within cooling systems. This in conjunction with the Health & Safety Executive Guidance Note EH40 details the safe concentration limits of CO_2 and in particular the threshold limiting value (TLV).

TLV information is given in the table below and compares CO_2 with others gases:

Refrigerant	Threshold Limiting Value			
	Long term exposure limit (8 hours)		Short term exposure limit (15-minutes)	
	ppm	mg.m-3	ppm	mg.m-3
R744 (Carbon Dioxide)	5000	9150	15000	27400
R717 (Ammonia)	25	18	35	25
R134A (Tetrafluoroethane)	1000	4240	NA	NA
R22 (Chlorodifluoromethane)	1000	3590	NA	NA

The following table plots CO_2 weight, volume and approximate system capacity, the actual capacity dependant on layout, pipe runs etc. Approximate concentration (ppm) based of a single 20kW cabinet's CO_2 (containing 6.21kg of CO_2); data is given taking account of the ventilation system (at 2 and 10 air changes per hour) which reduces concentration levels:

Cooling Capacity (kW)	CO_2 vol (ltrs)	CO_2 mass (kg)	Floor area @ 1500W/sq.m	Air mass @3.5m high x density	CO_2 ppm at 15 mins @ 2 a.c./hr	CO_2 ppm at 15 mins @ 10 a.c./hr
600	960	787	400	1792	1733	347
300	488	400	150	672	4621	924
150	250	205	75	336	9241	1848
80	134	110	40	179	17327	3465

As with conventional chilled water systems the CO_2 system will be subject to Pressure Systems Safety Regulations 2000 (PSSR 2000). In those instances the end user's consultant will prepare a 'Written Scheme of Examination' and carry out the first inspection of the installation prior to operation. Thereafter, annual inspection would usually be required to meet their obligations under the PSSR. Trox in association with its refrigeration partner are able to offer this consultancy service.

7.4 Procurement

The CO_2 Mission Critical Cooling system is available via a 3-tier procurement program. The capital plant and terminal equipment may be purchased through the following channels:

- Direct through an end user
- Facilities Management Contract
- Specialist Main or Services Contractor

Level One

The capital equipment which may include a chilled water system upgrade or a complete air or water cooled chiller along with the CO_2 system, plus the CO_2OLrac coolers may be purchased in a conventional manner.

Level Two

To reduce day-1 expenditure the package may be leased over a 24 or 36 month period. This offers the benefit of enabling a technology upgrade to take advantage of higher capacities and system enhancements.

Level Three

On-site R&D testing will aid strategic cooling direction. Testing includes supply, installation and removal of the system that includes up to four CO_2OLrac's, gas detection and isolation equipment; plus a technical report and recommendations.

7.5 Site Installation – Imperial College

The first installation of the system, by Trox and its refrigeration partner, is at Imperial College London in their E-Science Computer Suite in the Mechanical Engineering Building. The refurbishment project, in South Kensington, will see the system installed into the data suite during November 2005.

The system comprises of a combined air cooled R134a chiller and CO_2 plant (CO_2OLairpac), fully welded stainless steel secondary CO_2 distribution pipework, gas detection/isolation and cabinet coolers type CO_2OLrac. The system will provide 300kW of cooling, via 15off 20kW cool units.

To offer added flexibility of the space, the CO_2OLrac units are being supplied complete with an installation mounting frame. The solution enables the client to offer up various types/sizes of equipment cabinets as required during the operation of the space.

Imperial College London, Exhibition Road, Kensington

8 Professional Team

Client	- Imperial College London
M&E Services Consultant	- hurleypalmerflatt
Main Contractor	- Modus
CO_2 Contractor	- Star Refrigeration

9 Trademarks

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