THE INSTITUTE OF REFRIGERATION

Living without HFCs
The Danish Experience

by

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Status on the Danish situation

In the mid nineties there were strong movements in Danish political life to have a stronger environmental profile. Along with other initiatives, a ban of CFC, HCFC and HFC refrigerants was initiated and the last part was affected on the 1st of January 2007 with a general ban of all synthetic refrigerants. Since this is a general ban of all synthetic refrigerants it therefore also affects all new low GWP refrigerants as well.

There are a number of exceptions to the ban. The most signifiant exception is the 10kg limit. Systems with a charge higher than 150g and lower than 10kg can be built without any effect of the ban. The 150g limit is made to ensure that domestic refrigerators and similar equipment will not use synthetic refrigerants. The use of HFCs up to 10kg is allowed to ensure that small systems would not be too expensive. If the systems are fitted with heat reclaim the max charge is 25kg of HFC. Systems for transport applications are not affected by the ban.

It seems that the ban is working. Generally, systems are not being built with a larger charge than 10kg (25 kg), therefore the ban seems to be very effective. However, what is being seen is that the number of systems with charges below 10kg are growing. Which means that larger parallel systems are being substituted by several smaller systems with charge below 10kg. This is, of course, not the intention of the ban and the 10kg limit is but a consequence of the component situation.

Large companies have no problem adapting to the new situation, whereas smaller companies are struggling. This means in reality that small companies service existing systems and make small installations with charges lower than 10kg and the large companies make the bigger installations. This will probably change the refrigeration industry in Denmark since the small companies, over time, will disappear.

What are the major hurdles?

Basically there are two major hurdles for large systems. The biggest is probably developing the knowledge to build systems using alternative refrigerants and the other is getting components.

Over the last year or two the component situation for CO_2 has improved. Whereas before there was only one supplier, it is now possible to find several. This competition can also be seen at the pricing of components because the price is starting to come down to a level closer to HFC components. Due to the high pressure, components use more material but due to the capabilities of CO_2 they are often smaller and, therefore, the prices in some cases are lower than for HFC components. Today, the biggest hurdle on the component side is getting compressors of the right size. In general, compressors are available from 3.5 to 17 m^3/hr but to build smaller systems we need smaller and cheaper compressors. At the other end of the program we need bigger compressors to build large systems at a fair price.

The next problem is putting the components together. The pressures are higher and working with a transcritical refrigerant is different. Therefore, the knowledge gathered in R&D projects needs to be shared more widely. This will probably be the biggest task in the years to come.

Basically, CO_2 is not that different to other refrigerants but there are differences and manufacturers need to be aware of these so that high quality and reliable systems can be brought to the market.

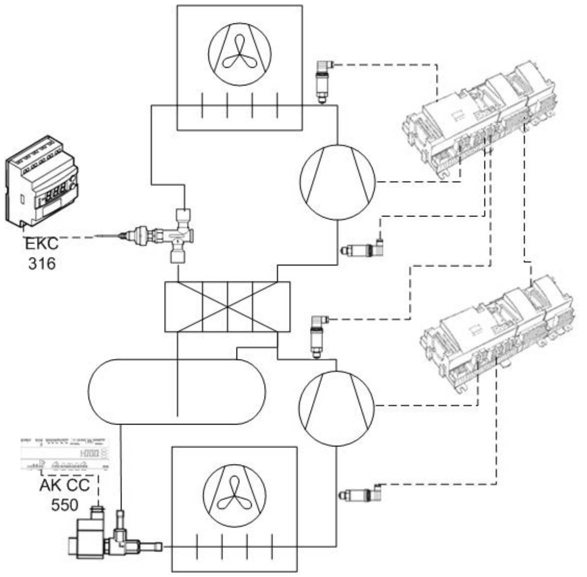
Normally, the pressure is considered to be a major hurdle. In reality, the pressure only causes small problems. The high pressure of the high side on transcritical CO_2 systems forces new jointing techniques and other materials in to the systems but, in reality, this is only a hurdle on the first systems. Then companies know how to handle this.

What systems are being built?

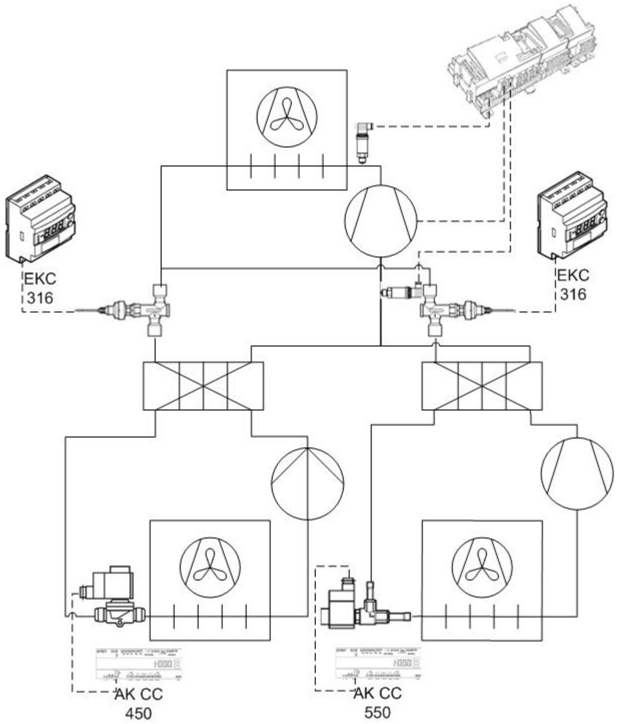
Cascade systems

Before the ban in Denmark there was at tax on HFC's and, therefore, the driver to changeover to CO_2 has been there for some years. This changeover happened first on low temperature systems where cascade systems very rapidly gained a large market share.

The first systems were CO_2 only for low temperatures or in combination with brine on medium temperatures.



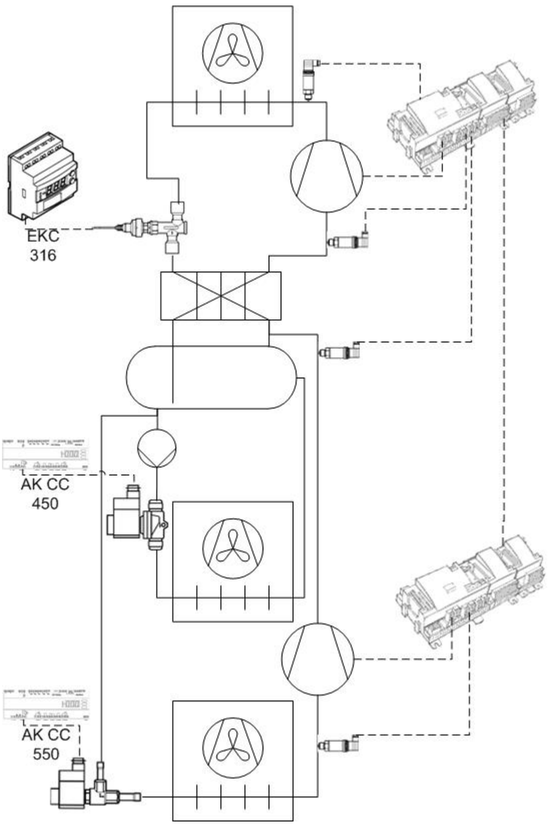
(System design 1)
Figure 1: Cascade system with CO_2 on LT



(**System design 2)**
Figure 2: Cascade system wit brine on MT and CO_2 on LT

Brine systems are widely used in other Nordic countries but in Denmark they were initially thought to be an easy solution. However, these have never become widely accepted. The reason for this is probably that the Danish industry is used to direct expansion and the conversion to brine was a big change in technology even though it seemed so simple.

To avoid brine systems CO_2 was used on medium temperatures as a pumped volatile brine.



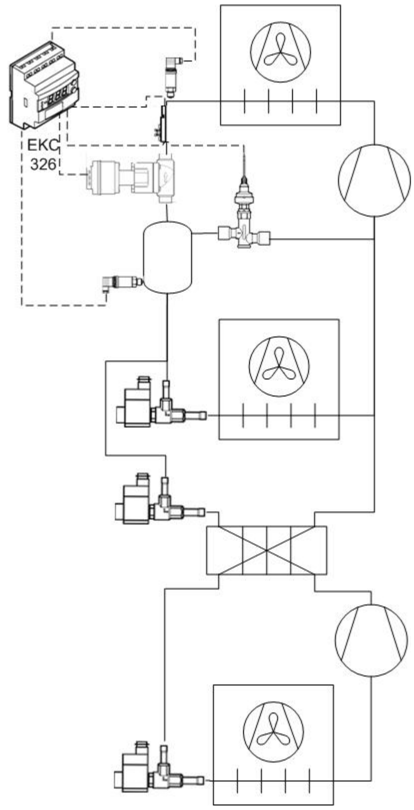
(System design 3)
Figure 3: Cascade system with pumped CO2 on MT and CO2 DX on LT

On paper, CO_2 seems to be a very difficult medium to pump because of the low gain of subcooling from the liquid column. Nevertheless, this is not a problem, in reality, due to the low energy in the cavitation with CO_2. Therefore, cavitation is an issue that needs to be handled with CO_2 but, in reality, is not causing many problems. The biggest problem faced in building cascade systems is to get the natural circulation up and running and performing the injection in the cascade heat exchanger. This is where we often see problems especially the first time a company is building such systems.

Systems with pumped CO_2 on MT and DX on LT are very common and are standard in all new Netto discount stores today. Energy consumption appears to be lower than brine systems. However, the complexity of the system makes it difficult for persons not used to this kind of installation to service.

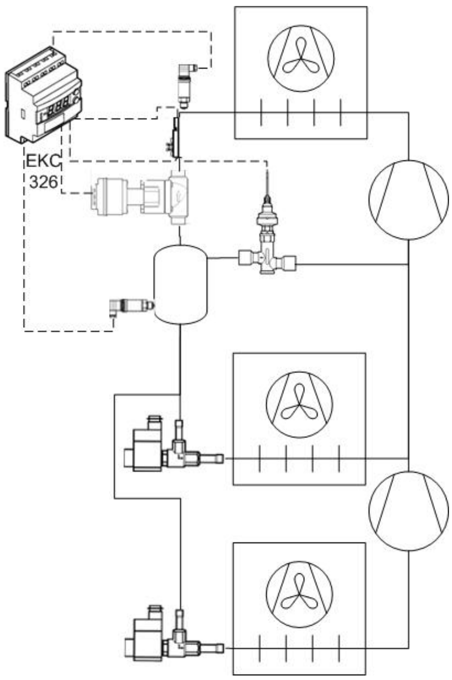
Transcritical systems
After the ban, cascade systems were also more difficult to build due to the demand for a low charge in the system or the changeover to hydro carbons. Therefore, transcritical systems are taking over a large share of the market. Currently, there are more than 100 transcritical systems in operation in the field in Denmark. Most of them have been built within the last 1½ years. Taking into account that approx 100 new systems a year are being built in Denmark the market penetration for transcritical systems has been very fast.

Generally there are two kind of systems being built.



(System design 4)
Figure 4: Transcritical cascade system with gas by pass

The cascade system was common in the first phase due to the lower demand for oil handling and the possibility to use different oil for low and medium temperatures. The complexity of the cascade system and the extra costs for expansion devices and heat exchangers is driving the market on to find other solutions.

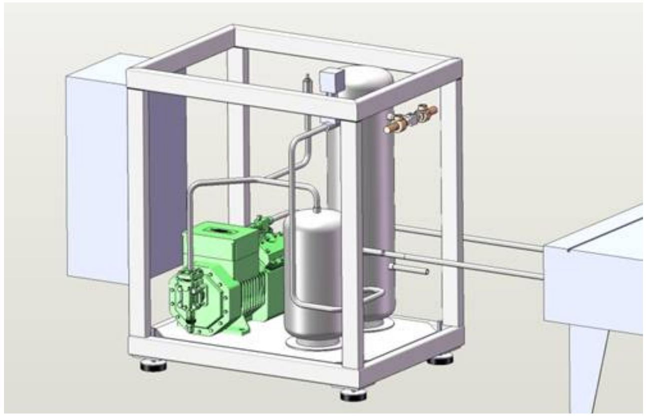


(System design 5)
Figure 5: Transcritical booster system with gas by pass

Today, most compressor manufacturers have released both LT and MT compressors with the same oil and, therefore, booster systems are a possibility. Normally for a mixed load of LT and MT there is no need for intermediate cooling and, therefore, the complexity of the system is very low. The gas by pass is used to bring down the pressure in the distribution system. Normally, the pressure in the receiver is 5-10 bar higher than the evaporation pressure for MT. Therefore, standard components can normally be used for 40 bar which are more or less off the shelf components. The high pressure side is normally designed for 100 or 120 bar depending on the application.

What will the future bring?
In this paper the future will be split in 6 parts- small systems, medium size systems, large systems, heat pumps, air-conditioning and finally cascade systems. That will be followed by a general summary.

Small systems
Small systems are something a lot of people thought was where CO_2 would take off but this has proven not to be the case. At the moment, there are no systems in operation with small capacity (<30kW) on a large scale. The main reason for this is that the price for small systems has proven to be very high compared to conventional systems. In the Nordic market this will happen in the years to come.



(System design 6)
Figure 6: Small transcritical system for gas station or small discount

Calculations based on the Danish market shows that this could be an attractive solution when the focus is not only on first cost but includes running and service costs. In these cases calculations show that it is economically feasible.

Medium size systems
Medium size (30 to 300 kW) systems is where CO_2 started to take off in 2007. At the moment, more than 100 systems are installed in Nordic countries and this concept seems to be taking over the market for supermarkets and light industrial systems due to low service and installation costs and slightly higher energy consumption compared to ammonia. Energy consumption in the Nordic region seems to be lower or at the same level as HFC systems. Cascade systems will probably be forced out of this segment due to the higher complexity of the systems and higher installation costs.

Large systems
Large systems have been dominated by ammonia in the Nordic region and many people thought that this would be ammonia and CO_2 cascades for the future and transcritical systems would not have a chance in this segment. However, now the first installations with transcritical CO_2 have started to appear.

(System design 7)
Figure 7: 1,2 MW installation in Norway

At this moment, two installations in the Nordic countries are being built both with capacities above 1 MW each. The reason for these installations is probably the high installation and service costs for ammonia. On top of this the high temperature from the systems can be utilised for heating and process. This is something we will be seeing more of in the years to come and we haven't seen the biggest systems yet.

Heat pumps

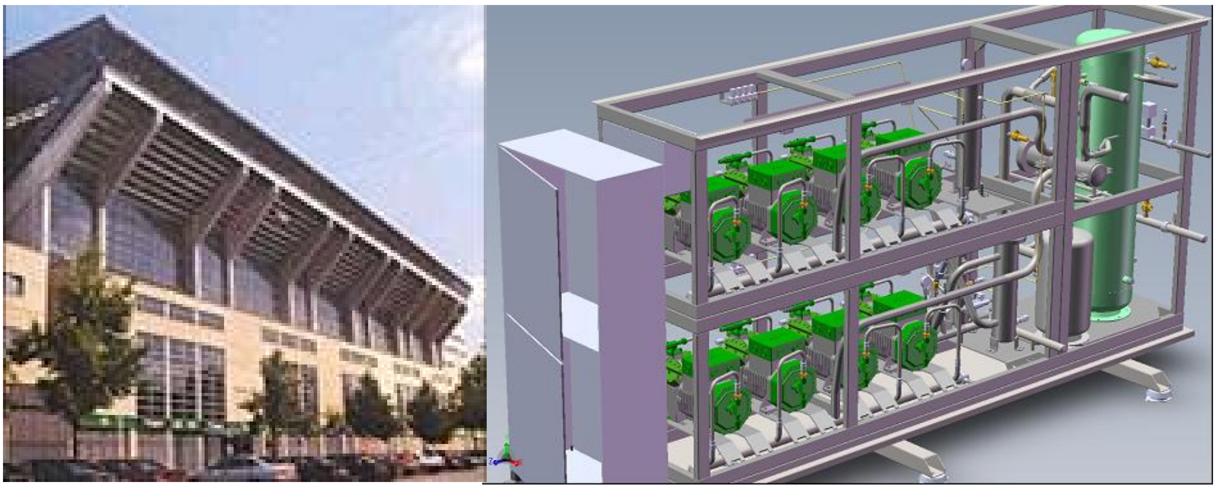
Heat pumps for domestic use are quite common in Japan, but not necessarily the best solution for the Nordic countries. If a high share of the heat is needed at high temperature, CO_2 is the right solution but if the biggest part is used for heating that can be done with 35-40 °C and at this temperatures conventional condensing refrigerants are superior.

The market for big industrial heat pumps will also start to emerge in the years to come. It is possible to make high temperature lifts and achieve high temperatures (80-90 °C) with high COP. There are some installations in the Nordic countries using this technology and with the focus on a more flexible power grid, CO_2 heat pumps for district heating could be an option. To make this really attractive a big compressor is needed.

Air-conditioning

Many years ago air-conditioning was dominated by turbo chillers, direct expansion and very large charges. This can again be a reality with CO_2.

In the picture shown below 3 x400 kW CO_2 will be installed for air-conditioning. The competition was won against a chiller / water brine solution. The transcritical DX solution has proven to be 20 % cheaper in installation and 15 % more energy efficient. The installation is



(System design 8)
Figure 8: Danish national stadium office building cooled with CO2 direct expansion.

cheaper due to smaller pipe sizes, and the energy efficiency is achieved by running the evaporation temperature from ~0 °C with water to ~7 °C with CO_2.

Cascade systems

Cascade systems will be a part of the refrigeration business for many years to come, but transcritical systems will most likely take a share of this market. Another problem the cascade systems will face is difficulty reaching high stand still pressures. The idea with cascade systems is that the pressure can be kept low but, if there is a power failure, the system is not capable of containing the CO_2 and will therefore over time loose the charge.

General Conclusions

Besides the trends stated above there will be several others to consider.

One very important trend will be pressure upgrading of systems. 40 bar systems are fine when there are only a handful of them but at the current time in Denmark alone there are 80 transcritical systems and cascades are in their hundreds. If there is a general power failure for a longer period there will be a substantial loss of CO_2 from these systems. If the number of systems is in the thousands there will not be enough CO_2 on the market to charge the systems again. This problem may not be the most likely scenario but needs to be addressed and one way to address it is to design for high standstill pressure (60-80 bar).

The future will bring big changes for the industry. It seems as if CO_2 could be the most enduring solution but this is impossible to know. It is most likely we will see a lot of different system designs living alongside each other. Cascade systems and transcritical systems will run alongside HFC systems for many years to come. Nobody knows what the future will bring but the experience in Denmark has proven that CO_2 is a good alternative to synthetic refrigerants where hydrocarbons seem to play a minor role due to flammability issues.

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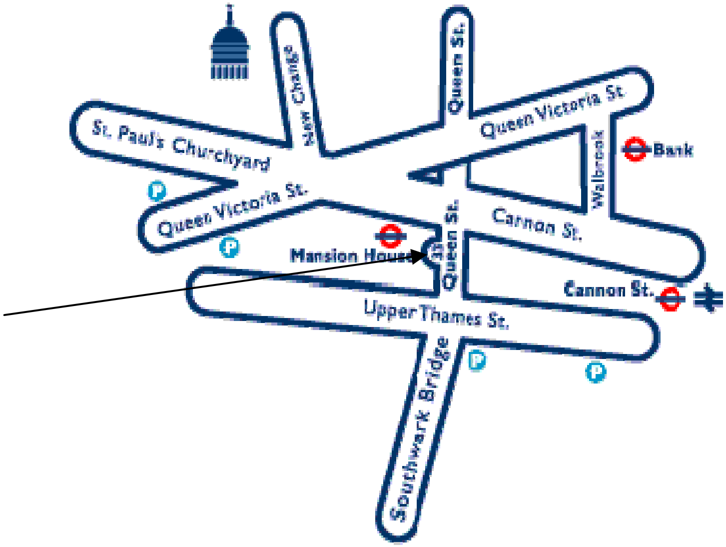

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