
Dogok Dong Condominium, Seoul, South Korea
Tallest Condominium – 3 Towers, 4,000 Luxury Apartment, Digital Scroll VRF Systems


ZhongHua Plaza, Guangzhou, China
Tallest Building In Guangzhou, 89 Floors, 296,000 m², Digital Scroll VRF Systems

Variable Refrigerant Flow Technology Options - DIGITAL SCROLL & INVERTER

Part 2 of 2

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In the first part of this article series, I had talked about an emerging trend in the air conditioning industry globally – the trend of capacity modulated (Variable Refrigerant Flow) air conditioning systems as a preferred choice for both residential and commercial applications. There are two technologies that can provide a/c system capacity modulation – inverter and Digital Scroll. In the first article, I explained how the Copeland Scroll works and the principle behind the operation of the Digital Scroll technology. I concluded the article by explaining some of the key advantages of the Digital Scroll technology. In this article, I am going to provide a more detailed analysis and comparison between the DC inverter and Digital Scroll. I am also going to discuss the challenge of measuring the energy efficiency of VRF systems and finally talk about the advances that are happening on the Digital Scroll platform – namely, equipping the Digital Scroll compressor with enhanced vapor injection technology.

Comparison of Digital Scroll and DC inverter (Scroll or Rotary based) technology

How the inverter compressor works

Before we go into the details of the comparison of the two technologies, we will explain briefly how the inverter technology operates. An

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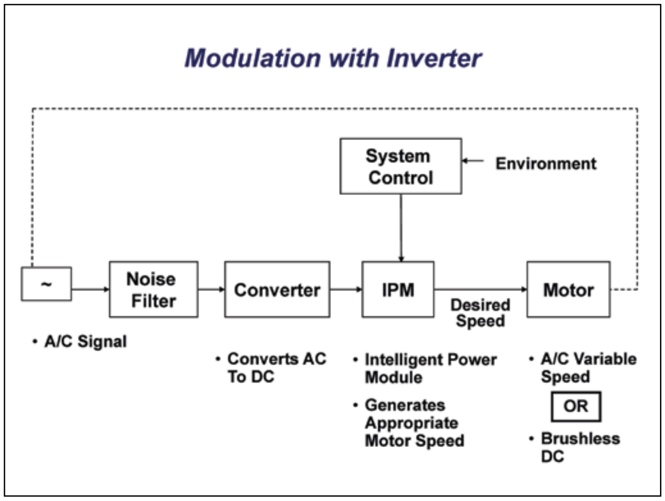

Chart 1: Modulation mechanism with Inverters

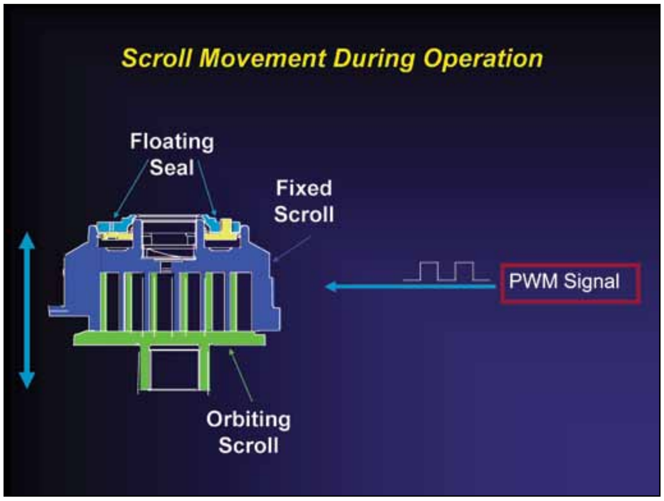

Chart 2: Scroll movement by 1.0 mm

inverter uses a variable speed motor on the compressor and an external inverter drive that provides the variable frequency/voltage to the compressor motor. When the motor gets the variable frequency signal – either through frequency (for AC inverter drive) or through voltage (DC inverter drive), it rotates at variable speed. So for the case of an AC inverter, if a 60Hz signal is given to the compressor motor, the compressor spins at 3,600 rpm. If the frequency goes to 90 Hz, the motor spins at 5,400 Hz. Depending on the manufacturer, the range of frequency delivered by the inverter driver can be from 28 Hz to 110 Hz. For the case of DC inverter, DC voltage is provided to the compressor motor to get variable speed and this can result in a motor speed of 30 r.p.s. to 90 r.p.s.

Chart 1 explains this conversion process pictorially and the energy losses that happen during the power conversion process.

The AC signal goes to a converter that changes the AC power to DC power. The system controller determines the amount of cooling that needs to be delivered by the compressor and that determines the compressor speed. The Intelligent Power Module (IPM) manages this requirement and converts the DC power to appropriate compressor motor speed. So, there are two conversions that can potentially take place. If the compressor has an AC motor, then the power is converted from AC – DC – AC. But if it is a DC driven motor, the power gets converted from AC – DC. Most of the inverter systems made today by the Japanese manufacturers are DC inverters and so losses only happen during the AC – DC conversion phase. This conversion loss can be anywhere from 7% to 15% depending on the manufacturer. Very good inverters will typically have 7% conversion losses. If there are two sets of inverter (as being sold in India through a leading Japanese OEM), then the losses are multiplied two times.

How the Digital Scroll compressor works

The beauty of Digital Scroll technology is its inherent simplicity. There are two scroll elements in the Copeland Digital Scroll – fixed scroll and orbiting scroll. During the normal compression process, the two scrolls are always held together with the optimal force in the vertical direction. However, through some mechanism, if the fixed scroll is made "unfixed" and is lifted by only 1 mm, there would be no gas compression even though the motor and the orbiting scrolls are moving. This is the simple mechanism of the Digital Scroll. The fixed scroll on the top is moved up by 1 mm (in order to get no compression) and pushed down and meshed with the orbiting scroll (in order to get compression). The up and down movement of the fixed scroll is achieved through a pressure differential/spring arrangement inside the compressor and is actuated by an external solenoid valve. A 220V to the external solenoid valve makes the fixed scroll go up by 1 mm and 0V to the solenoid engages the two scrolls back again. This is shown conceptually in *Chart 2*.

The Digital Scroll operates in two stages – the "loaded state", when the solenoid valve is normally closed (0V to solenoid coil) and "unloaded state", when the solenoid valve is open (220V to solenoid coil). During the loaded state the compressor operates like a standard scroll and delivers full capacity and mass flow. However, during the unloaded state, there is no capacity and no mass flow through the compressor and during the unloaded stage the compressor consumes only 10% of the full load power. The two states of the Digital Scroll are shown in *Chart 3*.

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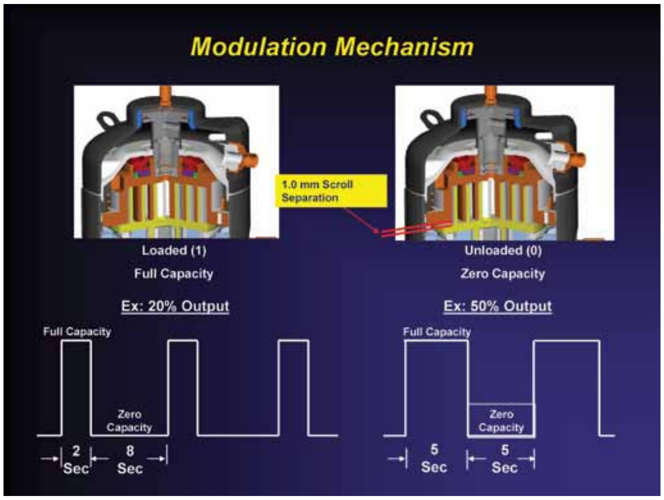

Chart 3: Loading and unloading of the Digital Scroll.

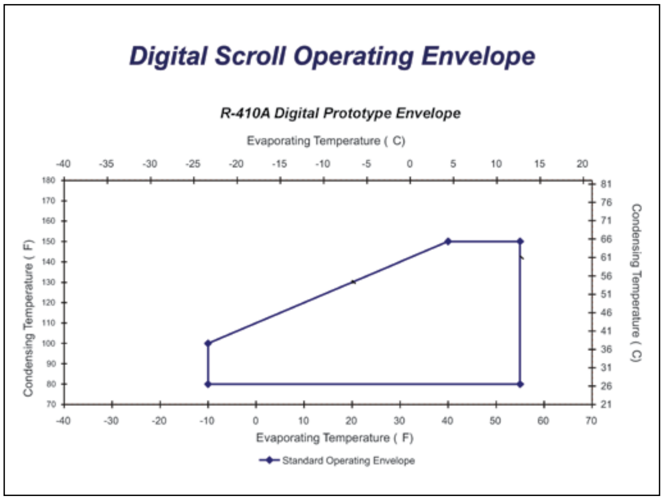

Chart 4: Operating envelope of Copeland Scroll.

At this stage, let us introduce the concept of a cycle time. A cycle time consists of a "Loaded State" time and "Unloaded State" time. The duration of these two-time segments determine the capacity modulation of the compressor. Example: In a 10 seconds cycle time, if the loaded state time is two seconds and the unloaded state time is 8 seconds, the compressor modulation is (2 seconds × 100% + 8 seconds x 0%) / 10 = 20% (*Chart 3*). If for the same cycle time, the loaded state time is 5.0 seconds and the unloaded state time is 5.0 seconds, the compressor modulation is 50%. The capacity is a time averaged summation of the loaded state and unloaded state. By varying the loaded state time and unloaded state time, any capacity (10%-100%) can be delivered.

Operating envelope of the compressor

The operating envelope of the Copeland Digital Scroll is shown in the following chart. Any compressor only sees the suction temperature/pressure and the discharge temperature/pressure. The saturated suction and discharge pressures are plotted as the x-axis and y-axis in *Chart 4*. The Digital Scroll compressor can operate anywhere within this operating envelope without any concern on the reliability.

The operating envelope of the inverter scroll is much more complicated. There are specific areas in the map that the inverter scroll cannot operate in due to the constraint on oil return, discharge temperature, etc. That is the main reason that the design of the inverter scroll/rotary is very complicated and it needs complicated algorithm to ensure reliable operation.

Simplicity of design

The Digital Scroll needs a 220V signal to modulate and provide variable capacity. The inverter technology, due to the inherent complexity, has a fairly complicated mechanical and electronic architecture. Following pictures will explain this more clearly.

Chart 5 shows an 8HP DC rotary inverter being sold

Chart 5 : DC rotary inverter system mechanical architecture.

Chart 6 : Mechanical architecture with Digital Scroll.

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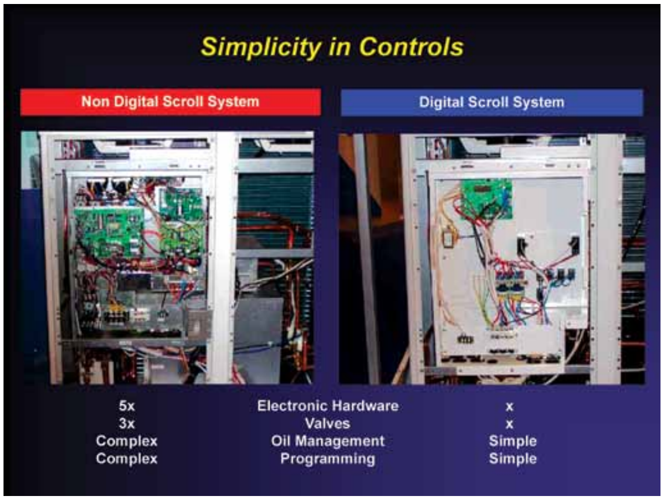

Chart 7: Electronic architecture comparison between Inverter and Digital Scroll

in India by a leading Japanese manufacturer. There are 11 solenoid valves in this system along with several other hardware for handling liquid refrigerant and oil.

There are probably several reasons behind this complex mechanical architecture – in this system, the compressor technology used is rotary and there are two rotaries and both of them are inverter driven. Typical rotaries are used in smaller room a/c systems and they are unable to handle large amount of liquids. Since VRF systems have a large amount of liquid, several layers of protection have to be built in to protect the system and that is one of the reasons the design engineer has used so many valves/bypasses/oil balance mechanism.

This can be compared with a 21Hp Digital Scroll system that has three compressors and *Chart* 6 shows the simplified mechanical architecture of this system.

The difference between the two technologies from an electronic architecture is also striking. *Chart 7* shows the DC inverter electronics on the left for a 10HP system and a similar electronic architecture for a Digital scroll system on the right. As can be easily seen, the simplification of the Digital based system is significant.

Oil return mechanisms

Digital Scroll: The oil return mechanism in the Digital Scroll is very simple. The normal oil circulation rate for a Copeland Scroll is around 1 percent. It means that 1 percent of oil leaves the compressor during the compression process. Oil circulation is measured as the percentage of oil in the discharge gas that leaves the compressor. In the case of the Digital scroll, oil only leaves the compressor during the loaded state. No oil leaves the compressor during the unloaded state. So the average oil circulation rate is always less than 1 percent. And even when the oil leaves the compressor during the loaded state, the gas velocity is strong enough to push and return the oil back to the compressor. So for any Digital Scroll system upto 6HP, there is no need to have any special oil recovery mechanism. For larger systems, where the pipe length can be over 150 meters, OEMs normally use an oil separator for added safety. The oil separator is a physical device that is brazed in the discharge line.

Inverter systems: All inverter systems need complicated oil return mechanism. The reason is the variable oil circulation rate in the inverter compressor. When the inverter compressor operates at 50HZ, it has an oil circulation rate in the range of 1-2%. At 50 Hz, the speed of the motor is approximately 3,000 rpm. At 90 Hz, the speed of the motor is well over 5,500 RPM and the oil circulation rate can be as high as 8%. Similarly, when the speed drops to 30 Hz, the speed of the motor drops to 1,800 HZ and the oil circulation rate can be less than 1%. Higher oil circulation means that more oil is now coating the surface of the heat exchangers and that reduces the heat transfer co-efficient of the heat exchangers and reduces the EER of the system.

At low RPM, there is not enough gas velocity to return the oil back to the compressor.

There are 2 methods that are employed in every inverter system – oil separator and oil return cycle. The oil separator is a physical device that is brazed at the compressor discharge to try to trap the oil and return it back to the suction line. But the oil separator has limited efficiency and so an oil return cycle is used.

Approximately, every two hours, the inverter compressor increases the speed of the compressor motor for about 10 minutes. During this period of 10 minutes, the mass flow and gas velocity of the refrigerant increases and it pushes all the oil that is residing in various parts of the system, including the long pipe length, to return back to the compressor. But this operation is not efficient. When the motor speed goes up, the input power consumption of the motor also goes up. The cooling capacity delivered also goes up. In case the room demand is not high, the bypass solenoid valves open to bypass the additional capacity. This is a complete waste of energy. The additional consumption of power to speed up the compressor motor is also a waste of energy. The consumer did not ask for the additional capacity. The system provided extra capacity and consumed extra power because it had to ensure that the oil is returned back to the compressor for safety reason. If the cumulative power consumption is measured over a one year period, all these wastages can be accurately accounted.

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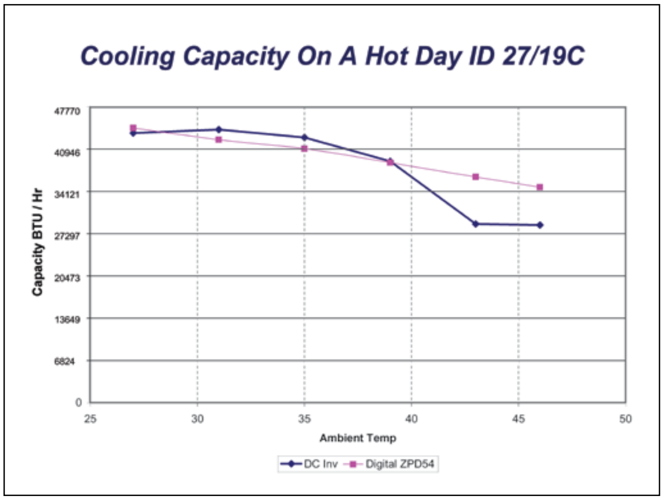

Chart 8: Cooling capacity at high ambient temperatures

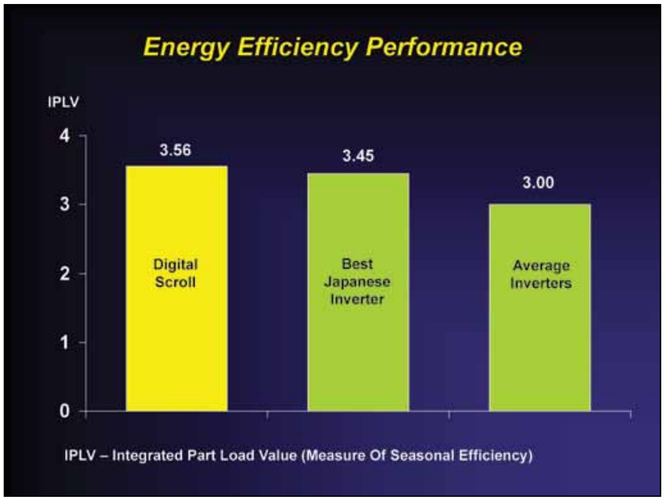

Chart 9: Comparison of Digital Scroll system, DC Scroll and DC rotary Inverter

High ambient operation

In countries like India and Middle East, ambient temperatures can reach very high during the peak of summer. It is not uncommon to see temperature close to 45°C in India and over 50°C in the Middle East. The Digital Scroll based VRF system demonstrates significantly better performance during high ambient operation as compared the DC inverter system.

A 5HP DC inverter system was tested in the Emerson testing facility. The indoor temperature was kept at 27°C dry bulb and 19°C wet bulb and the ambient temperature was slowly raised and the cooling capacity was measured. Once the DC inverter was tested, the DC Scroll compressor was taken out and the Digital Scroll was dropped-in to the chassis. So the test was a back to back test, done with the same hardware. Chart 8 shows the cooling capacity.

As can be seen from *Chart* 8, at temperatures above 40°C, the capacity of the DC inverter system started to drop sharply while the Digital Scroll based system continued to deliver higher capacity. The reason the inverter capacity drops is because at high ambient conditions, the compressor rpm increases significantly and as has been explained before, the inverter cannot operate at high speed for extended period of time. So the system cooling capacity drops due to reliability concerns. This is not desirable from an end user point of view, because when the room demand is high on a hot summer, the cooling capacity from an inverter system is inadequate.

Efficiency Performance/Life Cycle Cost Comparison

Measuring the energy efficiency of a variable capacity system (VRF system) is complex. The reason is that there are several variables that can be changed while doing the measurement. For example: the performance of the system will depend on the number of indoor units that are used during the testing of a multi split VRF system. If many indoor units with higher indoor air flow are used, the evaporating temperatures will be higher and the system EER will be higher. Since the capacity of the system is variable, the system can also be tested at lower capacities. At lower capacities, the condensing temperatures will be lower and the evaporating temperature will be higher. If the system is tested under such conditions, the system EER will be higher. This essentially means that reporting the performance of a VRF system is quite complicated.

The other complexity relates to the absence of a widely accepted standard for VRF systems. Typically VRF manufacturers have reported EER or COP numbers that are exceptionally high. These numbers are single point data and are reported at very benign test conditions (lower capacity, higher air flows, larger indoor coils, using a test mode that bypasses the inverter circuit etc). While these numbers look good in a catalogue, they are not a true measure of the real performance of the system. The seasonal performance has to be measured in order to do a real comparison.

ARI 210/240 and ARI 340/360 lays down a method of measuring the true performance of a variable capacity system. It recommends the measurement of Integrated Part Load Value (IPLV). IPLV measures the EER at four operating points – capacity steps of 100%, 75%, 50% and 25%. It then applies weight factors to each of these four points and summarizes a single number, called IPLV. For example: if the IPLV of a 10HP system were to be measured, four indoor units of 2.5 HP have to be used. EER data has to be measured at 100% capacity, when all the indoor units are ON. At the 75% point, one indoor

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unit is switched off and the EER is measured. At the 50% point, two indoor units are turned off and the EER is measured. For the 25% point, three indoor units are turned off and the EER is measured. Once these four numbers are measured, weight factors are applied and the IPLV is calculated.

A 10 HP Digital Scroll system was tested in an independent laboratory in China based on the IPLV standards and for comparison purpose, two other inverter systems were tested. The first was the latest DC scroll inverter system and the second was the latest rotary DC inverter system. *Chart* 9 shows the comparative performance of the three systems. This result has an interesting implication – "all inverters made by different manufacturers are not the same and they all have different efficiencies".

Life Cycle Cost

The energy efficiency of a VRF a/c system depends on a number of factors – the compression mechanism, the heat transfer components– coils and fans, and the mechanical and electronic architecture. The heat transfer is a relatively mature area and most OEMs have optimized their coil and fan technology to a very great extent. Further advancement and refinement to the heat exchange technology is going to be incremental improvements and not quantum performance jumps.

The factor that contributes a lot to the performance of a system is the mechanical and electronic architecture. The length of piping and the number of solenoid valves in the outdoor unit determines efficiency. Whenever long pipe lengths are there, pressure losses are certain to happen. Whenever gas passes through a solenoid valve, pressure losses are bound to happen. And any pressure loss on the low side affects the COP/EER of the system. The DC inverter rotary system has a significant length of copper piping in the outdoor unit. It also has 11 solenoid valves. From physics, we know that there will be pressure losses that will affect the COP of the system.

The electronic architecture is a good indicator of losses too. If large electronic boards and circuits are present in a machine, there are heat sinks that are provided. The heat sinks serve to dissipate the heat that is generated by the electronics. This heat is a waste and affects the COP/EER of the system. Larger the heat sink, more is the waste. The inverter systems have heat sinks and they are a waste of energy.

Oil recovery management in the inverter consumes excess energy. The compressor operates at high speed and the input KW increases. This is not desired by the end user and so is in effect a waste of energy.

Considering all these factors, it is clear that even IPLV is not a very good indicator of the true life cycle cost of a system. The energy losses associated with bypassing and/or oil recovery is never captured in the IPLV testing. But in a real life operation of a system, these functions happen regularly and contribute to the higher operating KW for the inverter systems.

Future of Modulation Technologies

As modulation technologies continue to become more popular, there are few technology advances that are being seriously looked into now – improving the heating capacity/ heating efficiency and improving the flexibility in usage/overall comfort factor to the end user.

Improving the Heating Function/Heating Efficiency

In many countries like China, Europe and Korea, heating is a major need and most VRF systems are sold as heat pumps. There are three most common ways to provide the additional heat:

1. *Electric Strip Heater:* Many systems are sold in the

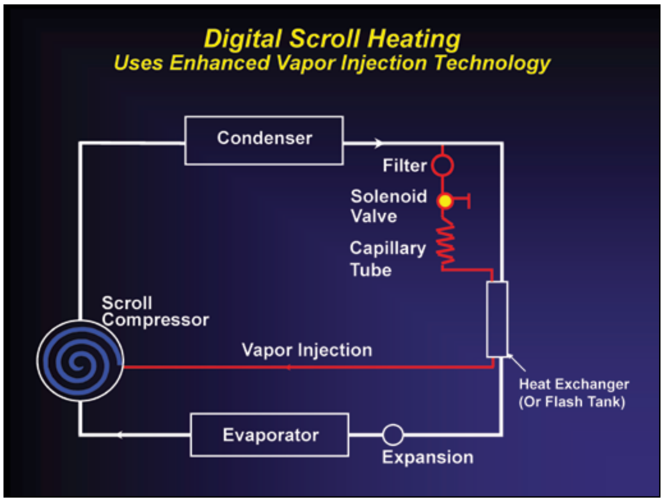

Chart 10: Principle of enhanced vapor injection.

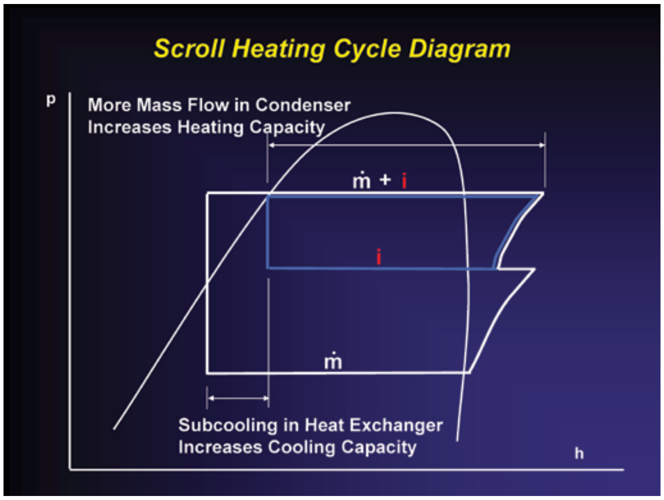

Chart 11: P-H diagram showing vapor injection cycle.

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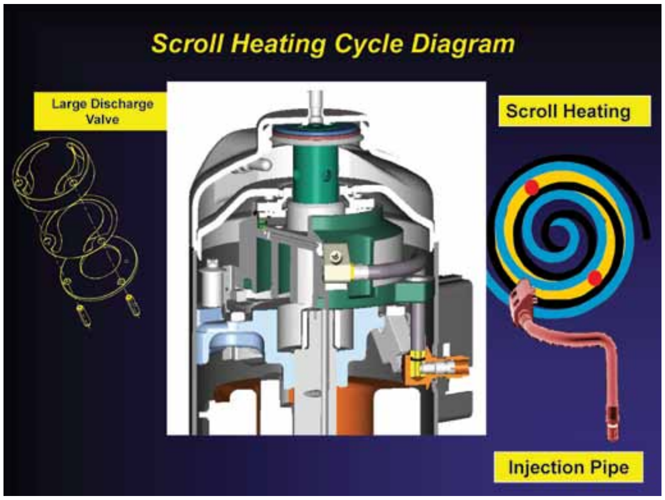
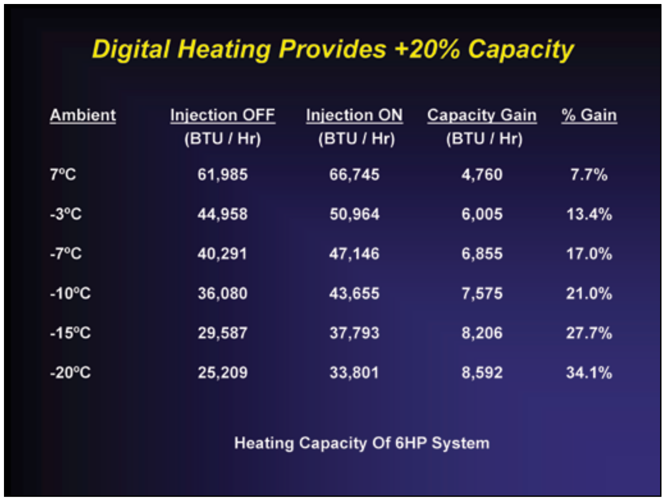


Chart 12 : Digital Scroll heating construction.



Digital Heating Provides +20% Capacity

Ambient	Injection OFF (BTU / Hr)	Injection ON (BTU / Hr)	Capacity Gain (BTU / Hr)	% Gain
7°C	61,985	66,745	4,760	7.7%
-3°C	44,958	50,964	6,005	13.4%
-7°C	40,291	47,146	6,855	17.0%
-10°C	36,080	43,655	7,575	21.0%
-15°C	29,587	37,793	8,206	27.7%
-20°C	25,209	33,801	8,592	34.1%

Heating Capacity Of 6HP System

Chart 13 : Heating capacity gain through vapor injection.

market today that have an electric strip heater placed near the indoor coil and it is activated if the ambient goes below a certain temperature. This method is inefficient, has safety hazard and lower reliability.

2. *Adding more compressor capacity:* Some systems are sold where the compressors are oversized and the additional compressor capacity is activated when the heating demand increases. During the standard cooling mode, the systems are rated at lower compressor capacity. This method has the disadvantage of lower efficiency because the system uses oversized compressor capacity and this results in a mismatch of all the a/c components.

3. *Overspeeding the compressor:* In VRF systems, the compressor goes on higher speed to deliver the additional heating. This method also has its limitation – the compressor cannot run on high speed for extended period of time and so there are times when the heating capacity delivered is not enough. Additionally, when the compressor overspeeds, it becomes a larger compressor with standard heat exchangers and so the COP drops sharply.

Emerson has introduced the enhanced vapor injection compressor to address the need of delivering additional heat at the most optimum COP. The principle of vapor injection is shown in *Chart 10*.

From the condenser outlet, a portion of the warm liquid is scavenged. This liquid is passed through an expansion device (shown as a capillary tube in *Chart 10*) and during the expansion process, the warm liquid becomes a chilled liquid. This liquid is then passed through a heat exchanger (either plate heat exchanger, tube in tube or a simple flash tank) and it mixes with the main liquid stream from the condenser. This process results in massive sub cooling of the condenser liquid and flash gas is generated. The flash gas is taken through another tube and injected in the intermediate cavity of the scroll set at an intermediate pressure (in between suction and discharge pressure). The increased subcooling of the main line condenser liquid results in increased capacity of the system. Additionally, since the scroll is injected with cooler gas, the discharge gas temperature is brought down and it allows the compressor to work at a higher compression ratio. Higher compression ratio is experienced during low ambient heating and so this technology allows the standard heat pump to work below –5°C.

The P-H diagram in *Chart 11* explains the thermodynamics of this process.

As can be seen from the ph diagram there are two cycles operating in the system – an increased mass flow of (m + I) that is circulating through the condenser that helps to increase the heating capacity of the system. Also, since gas at intermediate temperature

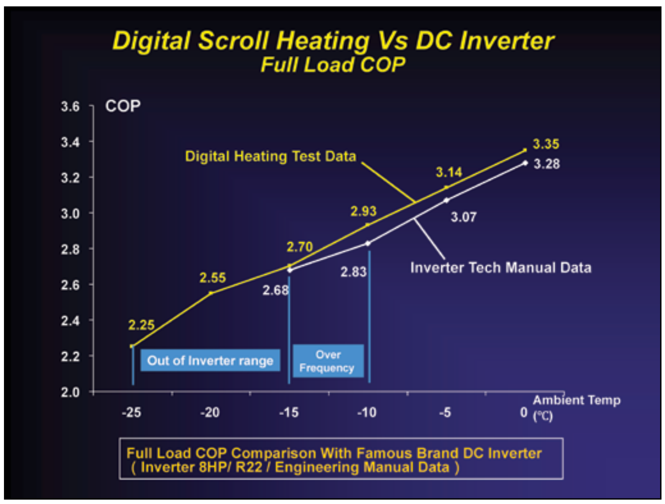


Chart 14 : COP comparison of Digital Scroll and DC inverter.

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and pressure is injected into the scroll sets, the scroll set final discharge temperature is lesser as compared to a cycle without the injection.

In the Digital Scroll heating compressor, the vapor injection technology is incorporated. The physical mechanism is shown in *Chart 12*.

There is an additional gas inlet that is provided on the shell of the compressor and a flexible tube is used to connect from the shell fitting to the top scroll. Two holes are drilled in the top scroll that provides a passage for gas to enter the intermediate cavity of the scrolls at an intermediate pressure.

The performance of the Digital Scroll heating compressor was evaluated in an a/c system. The system performance was measured with the Digital Scroll (with and without vapor injection). *Chart 13* shows the effect of the vapor injection technology for a 6HP system.

As can be seen from *Chart 13*, turning on the injection leads to a 20-30% increase in heating capacity.

Another set of testing was done to measure the COP of injection technology. *Chart 14* shows the COP as benchmarked against the DC inverter technology.

As can be seen from the above chart, the DC inverter start speeding considerably below –10°C to deliver the additional heating capacity but the COP drops. But when the ambient drops below –15°C, the DC inverter stops operating as it goes into the range of risky operation. Digital Scroll heating, due to the injection function, continues to deliver heating capacity, and that too at a COP of above 2.0 and that means there is considerably higher energy saving for the heating operation.

Summary

As can be understood from this article, comparison across several parameters shows that the Digital Scroll technology has some distinct advantages versus the Japanese inverter technology. Adopting new technologies to global markets will have to consider many geographical challenges – availability of a stable source of electricity, ambient temperatures, atmospheric cleanliness and the quality and availability of skilled technicians in the country. India has some distinct challenges and having an inverter system that has significant complexity of mechanical and electronic architecture is a long term reliability challenge. The Digital Scroll platform allows an OEM to build a highly reliable and efficient VRF system. There are technology enhancements being done on the Digital Scroll platform and the Enhanced Vapor Injection has proven to provide additional capacity in the most energy efficient manner. ❖

An Advt. appeared here