WHITE PAPER

2-STAGE AND DIGITAL SCROLL COMPRESSOR COMPARISON
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2-STAGE AND DIGITAL SCROLL COMPRESSOR COMPARISON

SUMMARY

When comparing packaged units, many technologies exist that make them different. To help with the decision process, this white paper provides a comparison of a 2-stage scroll compressor and a digital scroll compressor, examining the efficiency and humidity removal capabilities, along with some additional considerations, between the two types of compressors.

By reviewing several critical factors, often used in the decision process, this paper shows that a 2-stage compressor:

• Operates with greater efficiency, reducing utility consumption and system cost
• Removes a greater amount of humidity in many applications, leading to a more comfortable space
• Performs with greater reliability, reducing the likelihood of unscheduled service needs
INTRODUCTION

As a customer-focused manufacturer, Lennox strives to design and manufacture products focused around the total value to the customer through efficiency options, greater serviceability and proven reliability. In doing so, we constantly examine new and emerging technologies for their ability to improve efficiency, reliability and overall comfort in a space. Each component that goes into our systems must pass Lennox’ stringent criteria for performance and reliability. When selecting a compressor for our 3- through 5-ton Energence® rooftop units, many factors were taken into consideration prior to choosing to feature the 2-stage scroll compressor (2-stage compressor). This study examines how our unit with a 2-stage compressor compares to a similar unit with a digital scroll compressor (digital compressor).

2-STAGE SCROLL COMPRESSOR OPERATION

A 2-stage compressor functions in a similar way as a fixed scroll compressor with one major difference. In order to achieve part-load capacity, two bypass ports reduce the travel distance of the refrigerant through the scroll, allowing the compressor to operate at a low capacity of 67% of full capacity. To achieve part-load below 67% capacity, the compressor will simply cycle between low capacity and off.

DIGITAL SCROLL COMPRESSOR OPERATION

A digital compressor provides variable-capacity modulation by operating in two states, a loaded and unloaded state. (Please note, this is not the same as variable speed modulation.) During the loaded state, the compressor is engaged and acts like a standard scroll compressor, delivering the full capacity. When the compressor is in the unloaded state, there is no capacity. The unloaded state is achieved by opening a solenoid valve, forcing the rotating scrolls inside the compressor to become disengaged and unable to provide any capacity. By varying the time the compressor spends in the unloaded and loaded states, the capacity delivered by the compressor can range from 10% to 100% of full capacity. However, whether in the loaded or unloaded state, the digital compressor’s motor is always running, constantly using energy, unlike a 2-stage compressor which will cycle on and off to achieve part-load capacity below 67%.
In order to compare the efficiencies of a 2-stage compressor to a digital compressor, each compressor was simulated in a common system with only one difference. The 2-stage compressor was paired with a 2-stage fan while the digital compressor used a variable speed fan. The two systems were tested in multiple scenarios at 20%, 50%, 75% and 100% of total capacity, keeping the indoor temperature constant at 80°F dry bulb and 67°F wet bulb and varying the outdoor temperature. The overall system efficiencies were calculated, taking into account the efficiency losses from cycling the 2-stage compressor at lower capacities consistent with AHRI cycling test results.

Figure 1 shows the percentage difference of efficiencies from the digital compressor system to the 2-stage compressor system at the different capacities. A positive percentage shows greater performance of the 2-stage compressor system. At full capacity, both systems performed with negligible differences. However, at reduced capacities, the 2-stage compressor system performed with up to 44% greater efficiency, with the most drastic difference occurring at 20% capacity.

When compared, the overall SEER of the 2-stage compressor system is 12% greater than the digital compressor system from the difference in compressor alone, keeping all else the same except for the supply fan. When comparing actual systems, this difference is accounted for in the overall SEER rating (i.e., 18 SEER versus 15 SEER). In order for a manufacturer to offset this deficit, additional cost would need to be added to a system, causing the price to the customer to increase, or the manufacturer would offer a less efficient product. However, compressor efficiency does not provide the entire picture of the compressor comparison. In the next section, we examine the humidity control of the two systems.
HUMIDITY CONTROL

BACKGROUND

Figure 2 shows a plot of the latent and sensible capacity required to maintain a zone at 75°F and 50% relative humidity (RH) for a typical building in Ft. Worth, Texas. The vertical axis represents the latent (ability to dehumidify) capacity and the horizontal axis is the sensible (ability to change temperature) capacity. Each blue “X” on the chart represents one hour of a typical year for the condition of 15% outside air.

During operation, a thermostat sends a demand signal to a unit to maintain the zone setpoint temperature. However, since the thermostat is measuring temperature, it simply adjusts the average sensible capacity of the HVAC system to achieve the temperature needs of the zone. The latent capacity is a by-product and not based on the zone’s need.
HUMIDITY CONTROL (CONTINUED)

Figure 3 illustrates the latent capacity of a 5-ton unit as a function of the unit’s sensible capacity for both a 2-stage compressor system and a digital compressor system with the required levels to maintain a zone at 75°F and 50% RH overlaid. Since the 2-stage compressor system’s ability to remove humidity is dependent on how the indoor fan is run, both continuously running and cycling fan operations will be examined.

When the systems are running at higher capacities, the humidity-removal abilities of each system are similar. However, at 75% capacity, the systems’ abilities diverge.

![Figure 3](image)

2-STAGE COMPRESSOR – CONTINUOUS FAN

If a commercial application requires the supply fan to be operated continuously during occupied hours in order to provide the necessary ventilation, the operation has an unfortunate side effect. When the fan is running and the compressor is not, moisture sitting on the coil re-evaporates. The evaporation of the moisture transforms latent capacity into sensible capacity, reintroducing humidity to the space and reducing the net dehumidification potential of the system.

The “2-Stage – Continuous Fan” line on Figure 3 shows an estimate of the latent versus sensible capacity of a 2-stage system running with a continuous fan. At high sensible capacities, the two lines overlap indicating similar dehumidification. This is when the 2-stage compressor is cycling between low and high capacity. In this mode, the compressor is always on, so no re-evaporation occurs. Below approximately 30,000 BTU/hour, the system cycles the compressor between low stage and off.
HUMIDITY CONTROL (CONTINUED)

As the sensible capacity decreases, the compressor off time increases, allowing more time for re-evaporation. When the compressor is cycling on/off at equal intervals, there is theoretically no net dehumidification, because any moisture collected on the coil evaporates during the off cycle. However, in practice, some of the moisture collected can fall from the coil and drain out of the system, reducing the available moisture that can be re-evaporated and improving the humidity removal performance of a 2-stage compressor system with continuous fan.

2-STAGE COMPRESSOR – CYCLING FAN

If the supply fan is programmed to run only when cooling is needed, the humidity-removing capabilities greatly improve since no moisture will be reintroduced to the space, as shown through the “2-Stage – Cycling Fan” line in Figure 3. The only time the fan will run is when the cooling cycle is running and removing moisture from the air. This provides a linear relationship between sensible and latent capacity and allows this system to cover a vast majority of the performance demands for the sample building in Ft. Worth.

DIGITAL COMPRESSOR

Lastly, the “Digital” line in figure 3 shows the latent and sensible capacity relationship of the system with a digital compressor. Since the digital compressor allows capacity modulation down to 10% capacity, the compressor is always running. With the compressor always running, there is little opportunity for re-evaporation. However, on the digital compressor system, the latent capacity drops to near zero at 12,000 BTU/hour (25% capacity) due to the inability of the supply fan to slow down enough to maintain the same airflow rate per unit capacity. In other words, at 25% compressor capacity, the supply fan provides too much airflow for the given cooling need and re-evaporates some moisture back into the air, not allowing this unit to meet the performance needs of our sample building.

2-STAGE COMPRESSOR WITH HOT-GAS REHEAT

The need for dehumidification varies based on the application. Figure 4 depicts a hot-gas reheat system’s ability to remove humidity at a given sensible capacity, showing the same building in Ft. Worth with the blue “X” representing 15% outside air and the green “X” representing 30% outside air. In the 30% outside air state, the latent building load is greater than can be provided with a typical system. In humid climates, an indoor space can meet the required temperature but still be uncomfortably humid. In these situations, the previously discussed systems will not activate because cooling needs have been met and, therefore, will not be able to reduce the humidity levels, leaving the occupants uncomfortable.
If maximum humidity control or removal is needed, a 2-stage compressor system with hot-gas reheat, such as the Energence® rooftop units with the Humiditrol® dehumidification system, provides greater flexibility with temperature and humidity control. Figure 4 shows Humiditrol's greater humidity-removal capabilities over a wider range of capacities than the other systems described. This system is able to achieve these results because the cooling and humidity control functions can work independently or in unison. While other systems operate only when cooling is needed, providing humidity removal as a by-product, the Humiditrol system monitors the humidity levels in a space and will activate when humidity removal is needed, even if there is no cooling demand and without reducing the temperature in the space. From our tests, when humidity control is critical, the best option is a 2-stage compressor and fan with hot-gas reheat.
ENERGY USAGE

When making a purchasing decision, energy consumption is usually considered. Figure 5 depicts the energy consumption of the systems described in the previous pages. In this example, the hot-gas reheat system energy consumption corresponds to the maximum humidity removal. However, in most situations, as with the sample building in Ft. Worth, the demand for humidity removal is less than the system’s maximum capabilities and, consequently, will use significantly less energy.

While hot-gas reheat is the superior system to remove humidity in this study, it must be used with caution to avoid unnecessary energy consumption from setting the space’s RH below the actual need. ASHRAE suggests limiting the indoor RH to 60% or below.1 However, a relative humidity of approximately 50% is ideal when minimizing the impact of adverse health risks, such as viruses, dust mites, asthma and infections,2 increasing comfort, and reducing energy consumption.

The digital compressor system will consume the next highest amount of energy because even though the capacity of the compressor is decreased, the motor inside continues to move at the same speed.

Since the efficiency of the 2-stage compressor is superior to the digital compressor, the system consumes even less energy. The system with the continuous fan requires the least amount of energy since the process of evaporating moisture from the coil reduces the temperature of the air, providing some additional cooling while only consuming energy to run the fan.

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OTHER CONSIDERATIONS

RELIABILITY

2-stage scroll compressors have been described as being as reliable as a single-stage scroll compressor. However, this same statement is not applied regarding digital compressors.

In analyzing the technology, a number of factors stand out as potential reasons for this difference. First, in order to decrease capacity, the digital compressor needs to release a seal to "leak" refrigerant. Over time, after a number of sealing and releasing cycles, the seal can potentially degrade causing the loaded state and peak performance of the compressor to be negatively impacted. In addition, the function of varying the capacity on a digital compressor requires additional electronic components, which provide additional opportunities for failure. Also, the motor of the digital compressor runs at full speed for longer durations, causing the compressor to utilize its useful lifespan more quickly.

SMARTAIRFLOW®

Lennox® SmartAirflow® technology, offered on the Energence® 3- to 5-ton high-efficiency rooftop units, works in unison with the Prodigy® Controller to provide proper airflow to a building by monitoring the supply airflow from the building and outside. When equipped with the technology, an Energence unit can be customized with up to five different supply fan speeds, allowing the fan to meet a building’s ventilation requirement with the lowest speed possible. In a building with continuous fan operation, this permits the speed of the fan to be significantly decreased when only ventilation is needed. This also decreases the rate of re-evaporation for moisture back into the space and provides for better net humidity removal capabilities of a 2-stage compressor system with continuous fan operation. (For a complete account of all the benefits of the SmartAirflow System, please read the “SmartAirflow Supply and Ventilation Airflow Measurement” white paper.)

3“Modulation Technologies,” Emerson Climate Technologies, November 1, 2013.
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CONCLUSION

The research performed in this paper brings to light the strong advantages that a 2-stage compressor system has over a digital compressor system. Below are some final takeaways to consider when selecting a system:

- A 2-stage scroll compressor operates with greater efficiency than a digital scroll compressor, with 12% greater overall SEER rating when placed in similar systems, not taking into account other differences that can cause greater separation.

- A 2-stage scroll compressor system that cycles the evaporator fan with cooling demand or demand ventilation from CO₂ monitoring performs similarly or better than a digital scroll compressor system with humidity removal.

- When humidity control is mandated, a 2-stage scroll compressor hot-gas reheat system is far superior than a digital scroll system due to its greater humidity removal ability and the capability of controlling humidity without the need of a cooling demand or decreasing the temperature in the space.

- A 2-stage scroll compressor system can provide cooling while consuming less power than a digital scroll compressor system, and with proper configuration, the Humiditrol® dehumidification system can provide superior comfort with minimal power consumption impact.

- When considering reliability, a 2-stage scroll compressor performs more reliably from the start and avoids potential performance-hindering attributes of a digital scroll compressor.
APPENDIX A: GLOSSARY

Capacity, Latent: A unit’s ability to remove moisture from the air and decrease the wet bulb temperature of a space.

Capacity, Sensible: A unit’s ability to decrease the dry bulb temperature of a space.

Relative Humidity (RH): The ratio of actual moisture in the air to the maximum amount of moisture the air can hold for a given temperature and pressure.

Seasonal Energy Efficiency Ratio (SEER): An efficiency rating of a unit measured by the cooling output over a year divided by the energy consumption over that same duration.

Temperature, Dry Bulb: The temperature of air as measured by a thermometer without indication of humidity.

Temperature, Wet Bulb: A measure of the temperature of air if it were cooled to 100% RH by the evaporation of water into it. While the wet bulb temperature is lower than the dry bulb temperature, it approaches the dry measurement of air as the RH increases until they are equal at 100% RH.

Variable-Capacity Modulation: A compressor’s ability to change the capacity output.

Variable Speed Modulation: A compressor’s ability to change the capacity output by adjusting the speed of the internal motor.
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ABOUT LENNOX COMMERCIAL

Lennox Commercial is a leading provider of high-efficiency packaged rooftop units, split systems, HVAC controls, furnaces and indoor air quality products for the light commercial industry. Committed to helping our customers through advanced products and unsurpassed customer service, Lennox Commercial delivers effective HVAC solutions that improve comfort and protect profits.

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