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Reducing AC Power Consumption By Compressor Downsizing on a Sports Utility Vehicle

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REDUCING AC POWER CONSUMPTION BY COMPRESSOR DOWNSIZING ON A SPORTS UTILITY VEHICLE

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ABSTRACT

Reducing AC power consumption in an automobile is one of the key challenges for climate control engineers. The AC compressor consumes power from the engine which directly affects fuel economy and vehicle drivability. The main objective of this study is to reduce front end auxiliary drive (FEAD) load on engine by compressor downsizing, without compromising on cooling performance of the AC system. The study has been carried out on a sports utility vehicle (SUV) which has twin evaporator AC system. The three compressors under study have been critically evaluated at three levels a) Component level b) System level and c) Vehicle level. The study has been conducted in two phases 1) downsizing from 170 cc/rev reciprocating piston compressor to 130 cc/rev compressor and 2) further downsizing from 130 cc/rev reciprocating piston compressor to 90 cc/rev rotary scroll compressor. The results of this study demonstrate that AC power consumption and refrigerant quantity are reduced by 25% and 5% respectively.

Key words: Automobile climate control, front end auxiliary drive load, power consumption, compressor downsizing.

1. INTRODUCTION

One of the primary functions of an automobile climate control system is to provide the desired cooling and stabilise cabin temperatures to comfortable levels in hot climatic conditions. With the increasing demand for more energy efficient systems and thermal comfort in automobiles, the automobile AC system needs to be optimized to deliver the required cooling performance with minimum AC power consumption. Proper selection and integration of AC compressor with other system aggregates results in improved energy efficiency of the system.

Geon and Tae (2004) have mentioned about the importance of AC power consumption reduction in their study. Urchueguia *et al.* (2003) have carried out experiments with scroll and reciprocating compressors using R22 and propane as refrigerant, for a commercial type refrigeration unit of nominal capacity of about 20kW. Kapoor et al. (2004) have carried out experiments with reciprocating and scroll compressors on a small car automotive air conditioning system and found that 60 cc/rev scroll compressor delivers an equivalent cooling with 20% reduction in power consumption as compared to a 110 cc/rev reciprocating piston compressor. Perevozchikov and Pham (2004) have shown that variable speed scroll compressor gives superior performance over conventional compressors in terms of efficiency and reliability.

The SUV considered for this study is originally equipped with 170 cc/rev reciprocating piston compressor. The study of various compressors shows that for the same application, a smaller capacity compressor can be used to reduce AC power consumption and still can maintain the same level of cooling by optimizing the AC system aggregates. In addition, by deploying scroll compressor technology, the compressor capacity can be further downsized, making the system even more energy efficient.

In case of conventional reciprocating piston type swash plate compressors, frictional losses are high due to the reciprocating motion of pistons past the walls of the cylinders, resulting in lower efficiencies. In case of a scroll compressor, its typical internal construction and compression mechanism reduces the frictional losses and increases the efficiency. In a scroll compressor, there are two spiral-shaped scroll members, one stationary scroll and the other scroll orbiting relative to the stationary scroll. These two members fit together forming crescent shaped pockets. As the orbiting motion continues, refrigerant is drawn in from the outer ends and forced toward the center of the scroll form gradually increasing refrigerant pressure. The high pressure refrigerant is then discharged from the center port of the fixed scroll member.

2. METHODOLOGY

The methodology adopted for this study is to experimentally evaluate the power consumption and cooling performance of the three AC compressors under study at three different levels a) component level calorimetric test b) system level bench test and c) vehicle level dynamometer test. This study has been carried out in two distinct phases.

2.1 Phase 1:

In phase 1, 170 cc/rev reciprocating piston compressor is compared with 130 cc/rev reciprocating piston compressor. Both these compressors have similar technology and are similar in construction. For 130 cc/rev compressor, the AC system has been reconfigured with change in capacity of thermostatic expansion valve and refrigerant charge quantity as compared to the existing AC system.

2.2 Phase 2:

In phase 2, 130 cc/rev reciprocating piston compressor is compared with 90 cc/rev rotary scroll compressor. These two compressors are different in both, technology and construction. There is no change in the system configuration and refrigerant charge quantity for these two compressors.

3. TEST CONDITIONS

3.1 Compressor Calorimetric Test

All the three compressors under study are tested as stand alone on a compressor calorimeter, under identical test conditions (LP=1.76 bar, HP=16.4 bar, SH=10°C, SC=5°C). The set points represent the typical vehicle operating conditions. The compressor cooling capacity and power consumption are evaluated at four different engine speeds.

3.2 System level Bench Test

The experimental set up consisted of original components from the R134a system of a typical twin evaporator AC system of SUV. The set up as shown in Figure 1 consists of three environmental chambers for the compressor, condenser and evaporator. The compressor drive motor is housed in a fourth chamber.

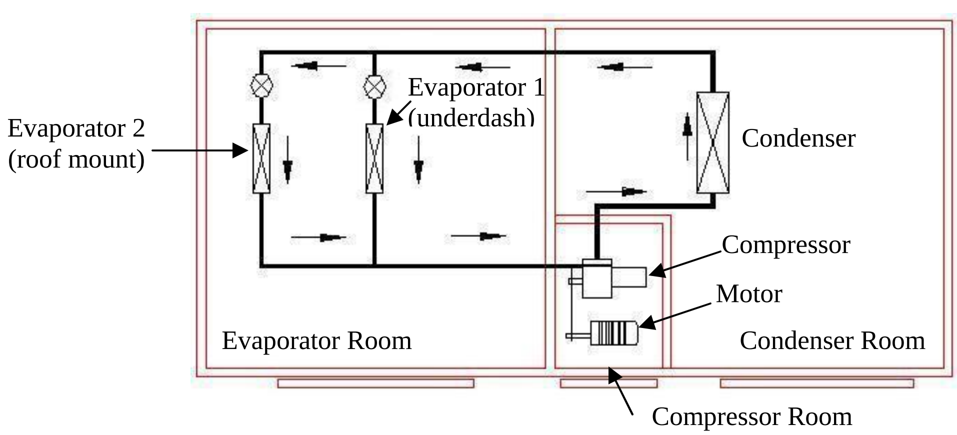

Figure 1: Schematic diagram for Bench test set up

The compressor chamber holds the compressor at a desired temperature to simulate temperature conditions in the engine compartment of the car. The compressor is run by the electrical motor acted upon by frequency converter in order to cover the whole range of rotational speed in the actual vehicle. Condenser and evaporator chambers contain a wind tunnel with variable speed blower and temperature controller, enabling a wide range of air flow rates and temperatures for the condenser and evaporator chambers respectively. The evaporator chamber also has a steam supply and humidity controller to provide latent heat load. In addition the evaporators are kept in the original plastic casing to preserve the same air circuit and flow rate as in the actual vehicle.

The test condition is designed to represent actual vehicle operating conditions. On the test bench, the compressor speeds for all three compressors were set corresponding to engine speed as on the vehicle. There are five engine speeds from 950 rpm to 4000 rpm simulating vehicle idling to high cruising speeds. The ambient air around the compressor is maintained at 100°C and the condenser at 45°C. Air flow rate across the condenser is related to vehicle speed. In stationary idling condition, the velocity is restricted to 1 m/s whereas at cruising speed of 80 kmph, the velocity is set to 4.5 m/s. The inlet air condition for the evaporator is 35°C / 60% RH. Air flow rate set over evaporator 1 is 400 m^3/hr and over evaporator 2 is 180 m^3/hr. These typically are the air flow rates at the maximum blower speed for a twin evaporator AC system of SUV. In the bench test, cooling capacity and power consumption of the AC compressor at the system level has been evaluated across engine speeds.

3.3 Vehicle level dynamometer Test

The SUV is tested on a chassis dynamometer with the three compressors. The tests are conducted under identical test conditions to evaluate the AC power consumption. The tests are done at five vehicle speeds in 5th gear full throttle condition. To ensure that the AC system is fully loaded and the compressor works continuously during the test, the windows are kept open and the anti-icing device is bypassed.

4. EXPERIMENTAL RESULTS

4.1 Phase 1: 170 cc/rev compressor (reciprocating) vs. 130 cc/rev compressor (reciprocating)

4.1.1 Compressor Calorimetric Test: Figure 2 shows comparative performance of the two compressors in the compressor calorimeter. The power consumption of 130 cc/rev compressor is 5% to 18% lesser than 170 cc/rev compressor across engine speeds. The result also demonstrates that cooling capacity of 130 cc/rev compressor is lesser by 13% to 24% than 170 cc/rev compressor as stand alone component.

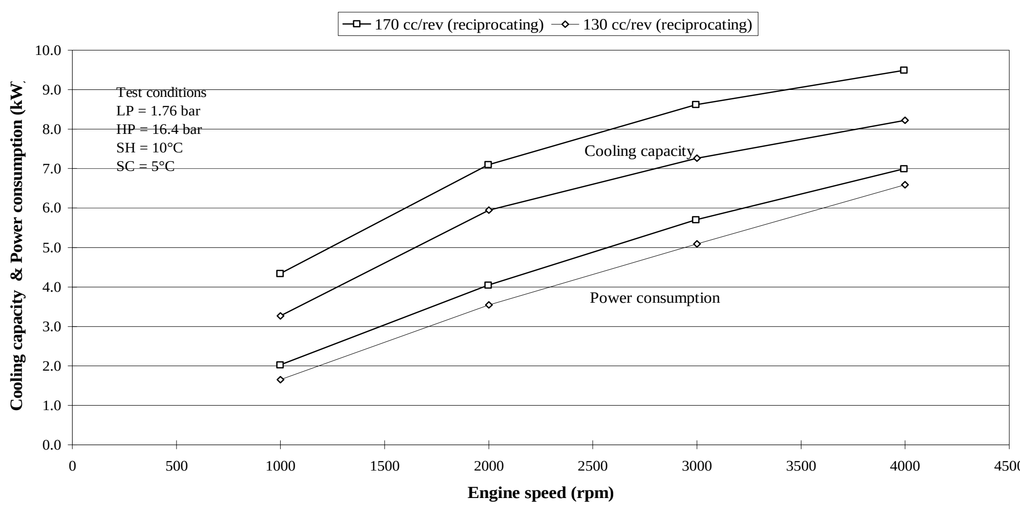

Figure 2: Compressor calorimetric test – 170 cc/rev vs 130 cc/rev

4.1.2 System Bench test: Figure 3 shows the bench level performance of the two compressors. The result demonstrates that power consumption of 130 cc/rev compressor is lower by 1% to 9% below 2500 rpm and higher by 2% to 5% above 2500 rpm compared to 170 cc/rev compressor. The combined cooling capacity of the twin evaporator system with 130 cc/rev compressor is lower by 3% compared to 170cc/rev compressor below 1750 rpm and higher by 2% above 1750 rpm.

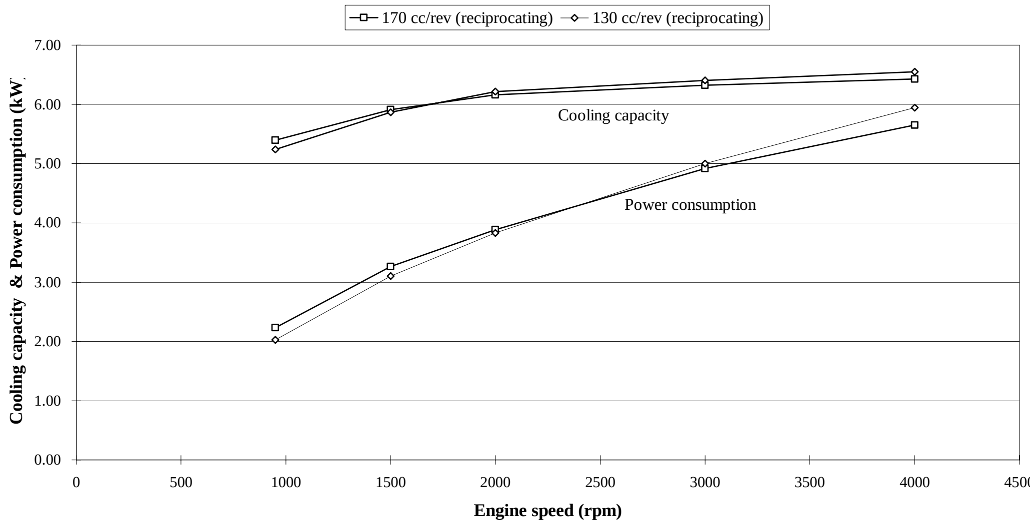

Figure 3: Bench test – 170 cc/rev vs 130 cc/rev

By optimising the capacity of thermostatic expansion valve and refrigerant charge quantity, the 130cc/rev compressor when coupled with other AC system aggregates delivers the same cooling performance as 170 cc/rev compressor with less power consumption. This demonstrates that 130 cc/rev compressor is better optimised with the other AC system aggregates.

The refrigerant charge quantity for the twin evaporator system with 130 cc/rev compressor is reduced from existing 950 gms to 900 gms.

The 170 cc/rev compressor, which delivers higher cooling capacity at component level (stand alone), delivers lower cooling performance when coupled with other AC system aggregates. This demonstrates that 170 cc/rev compressor is overcapacity for the existing AC system.

4.1.3 Vehicle level dynamometer test: Figure 4 shows the AC system power consumption across vehicles speeds with 170 cc/rev compressor and 130 cc/rev compressor. Test results demonstrate that 130 cc/rev compressor consumes 8% to 15% lesser power compared to 170 cc/rev compressor. This reduction in power consumption is achieved with the same level of cooling performance.

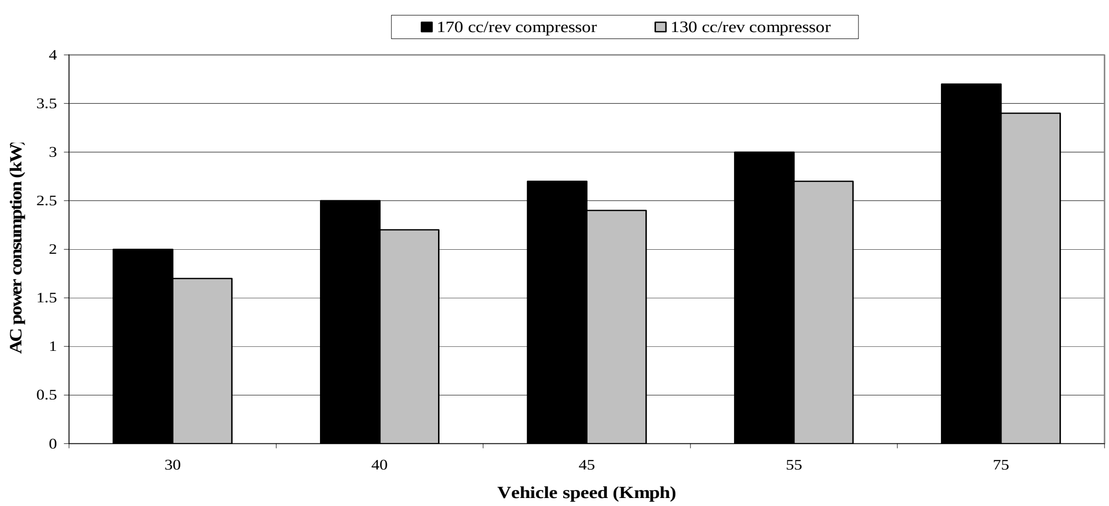

Figure 4: Chassis dynamometer test – 170 cc/rev vs 130 cc/rev

At the end of phase 1, the test results demonstrate that at all three levels 130 cc/rev compressor consumes lesser power as compared to 170cc/rev compressor. The results also show that after optimising the AC system aggregates, 130 cc/rev compressor delivers same cooling performance as that of 170 cc/rev compressor. Based on these advantages, 170 cc/rev reciprocating compressor has been replaced by 130 cc/rev reciprocating compressor on the vehicle.

4.2 Phase 2: 130 cc/rev compressor (reciprocating) vs. 90 cc/rev compressor (scroll)

4.2.1 Compressor Calorimetric Test: Figure 5 shows comparative performance of the two compressors in the compressor calorimeter. The power consumption of 90 cc/rev scroll compressor is 2% to 13% lower than 130 cc/rev reciprocating compressor across engine speeds. The result also demonstrates that cooling performance of scroll compressor is 4% to 30% higher than reciprocating compressor as stand alone component. The performance curves for 170 cc/rev compressor are shown with dotted lines for reference.

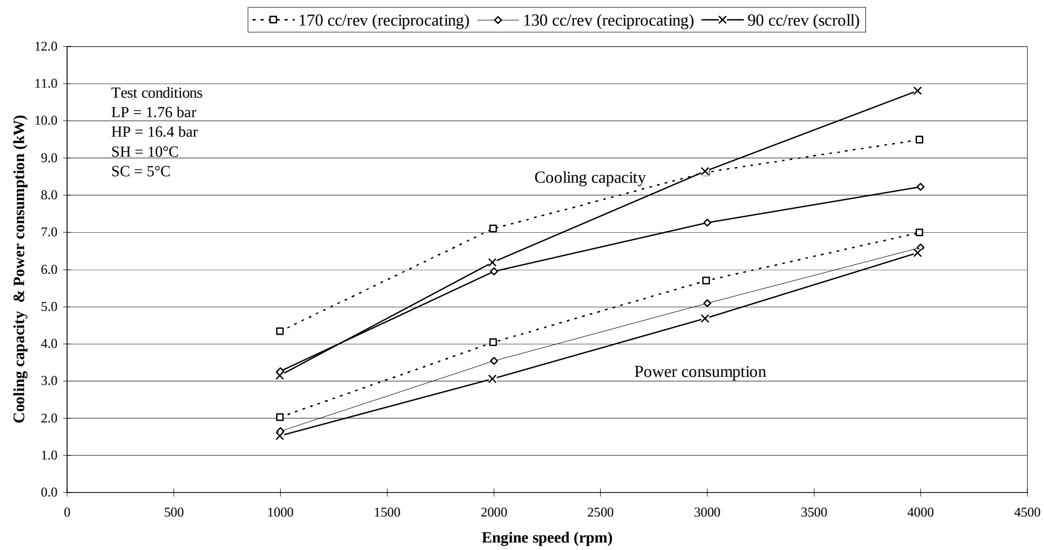

Figure 5: Compressor calorimetric test – 130 cc/rev vs 90 cc/rev

4.2.2 System Bench Test: Figure 6 shows the bench level performance of 130 cc/rev reciprocating and 90 cc/rev scroll compressor. The power consumption of scroll compressor is lower by 5% to 20% compared to reciprocating

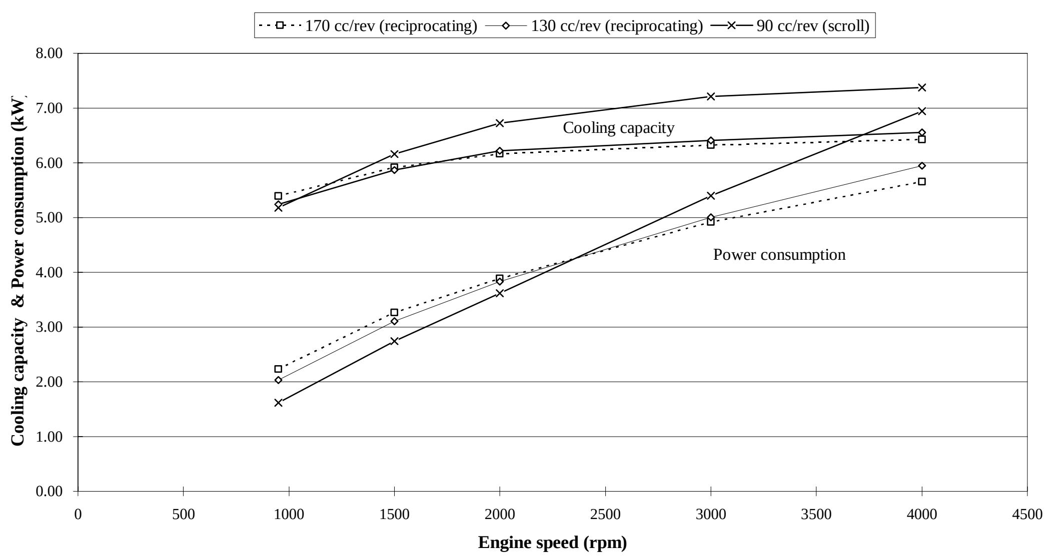

Figure 6: Bench test – 130 cc/rev vs 90 cc/rev

compressor below 2400 engine rpm. The combined cooling performance of twin evaporator system with 90 cc/rev scroll compressor is higher by 4% to 12% compared to 130 cc/rev reciprocating compressor across engine speeds. Without making any modifications in the system and with same refrigerant charge quantity (900 gms) as that of reciprocating compressor, the scroll compressor delivers more cooling performance with less power consumption. The scroll compressor which delivers higher cooling performance at component level (stand alone), once again demonstrates higher cooling performance when coupled with other AC system aggregates at bench level. This shows that scroll compressor is well optimised with AC system aggregates. The performance curves for 170 cc/rev compressor are shown with dotted lines for reference.

4.2.3 Vehicle level dynamometer test: Figure 7 shows the AC system power consumption across vehicles speeds with 130 cc/rev reciprocating compressor and 90 cc/rev scroll compressor. Test results demonstrate that scroll compressor consumes 16% to 25% lesser power compared to reciprocating compressor. This reduction in power consumption is achieved with the same level of cooling performance. The values for 170 cc/rev reciprocating compressor are also captured for reference.

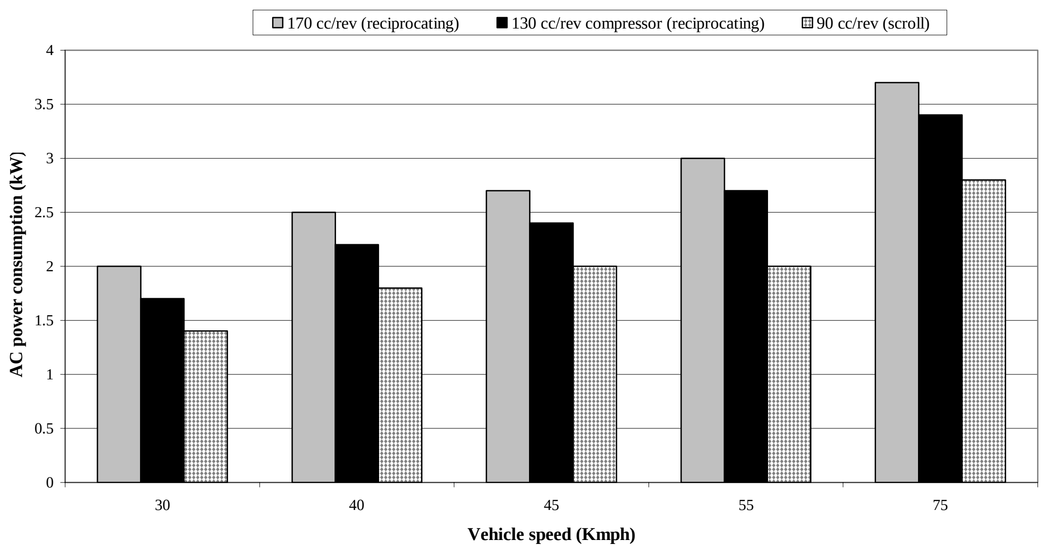

Figure 7: Chassis dynamometer test – 130 cc/rev vs 90 cc/rev

At the end of phase 2, the test results demonstrate that at all three levels 90 cc/rev scroll compressor consumes lesser power compared to 130 cc/rev reciprocating compressor. It also shows that 90 cc/rev scroll compressor delivers higher cooling performance than that of 130 cc/rev reciprocating compressor with no change in the AC system aggregates. Based on these advantages, 90 cc/rev scroll compressor has been recommended to replace 130 cc/rev reciprocating compressor.

5. CONCLUSIONS

The main focus of the present study is reduction in the AC power consumption by compressor downsizing. A methodical approach of three way experimental evaluation in two phases has been followed to realize the objective.

- In phase 1, by downsizing the AC compressor from 170 cc/rev to 130 cc/rev capacity, 8% to 15% reduction in power consumption is achieved.
- In phase 2, by downsizing the AC compressor from 130 cc/rev to 90 cc/rev capacity, 16% to 25% reduction in power consumption is achieved.
- Overall, there is 24% to 30% reduction in AC power consumption by replacing 170 cc/rev reciprocating compressor with 90 cc/rev scroll compressor. The lower power consumption of scroll compressor can be attributed solely to its internal construction, compression mechanism, and lower frictional losses.
- Furthermore, there is 5% reduction in refrigerant charge quantity because of compressor downsizing.

All these benefits are achieved without any deterioration in the AC cooling performance. The scroll compressor offers the added benefits of low noise, higher continuous speeds and improved drivability. Advancements in compressor technology offer opportunities to further reduce the AC power consumption and refrigerant charge quantity.

ABBREVIATIONS

HP	High pressure
LP	Low pressure
RH	Relative Humidity
SC	Sub cooling
SH	Superheating
AC	Air conditioning

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