

## EFFECT OF INNER COMPRESSION RATIO ADJUSTMENT ON SEASONAL ENERGY PERFORMANCE OF INVERTER AIR CONDITIONER

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### ABSTRACT

The inherent feature of fixed inner volume ratio of the scroll compressor causes large degradation of the compressor's indicated efficiency when the inner compression ratio mismatches with the system compression ratio under the off-design condition. The inner compression ratio adjustment technology, such as refrigerant injection and refrigerant release, can enhance the seasonal efficiency of the compressor and the air conditioner. An inverter air conditioner with inner compression ratio adjustment is proposed in this paper. Through a seasonal simulation, a conclusion can be made: the implement of inner compression ratio adjustment can decrease the power consumption of the air conditioner 10%~25%.

### BACKGROUND

The room air conditioner is widely used in the residential building. Enhancing the energy efficiency of the room air conditioner is an important way to realize the energy-saving of the residential building.

Compared with the chiller in large public building, which usually uses the cooling tower as the heat rejection equipment, the room air conditioner discharges the heat into the circumstance air through the condenser, directly. Therefore, the condensing pressure and energy efficiency of the room air conditioner are heavily affected by the dry bulb temperature of the environment while the ones of the chiller are affected by the wet bulb temperature. Because the variation of the wet bulb temperature is much smaller than the dry bulb temperature, as a result, the working condition of the room air conditioner will vary in a much larger range in comparison with the water cooled chiller, which leads to the system compression ratio (SCR, equals to  $P_{condenser}/P_{evaporator}$ ) of the air conditioner varying in a large range.

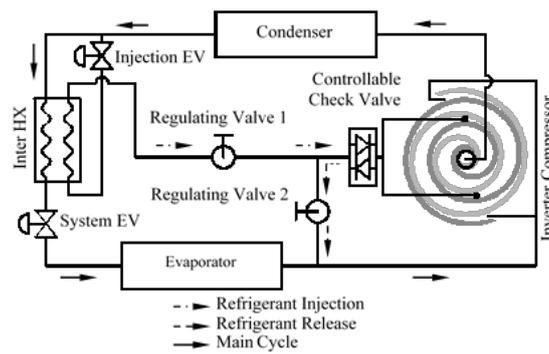
The scroll compressor is the mainstream compressor for the room air conditioner due to its high efficiency under the design condition. However, the inherent feature of fixed inner volume ratio (equals to  $V_{suction}/V_{discharge}$ ) causes large degradation of the scroll compressor's indicated efficiency when the inner compression ratio (ICR, equals to  $P_{discharge}/P_{suction}$ ) mismatches with the SCR under the off-design condition, which is confirmed as the maximum barrier for pursuing high seasonal energy performance. Some investigations have been conducted to enhance the inner compression efficiency, which is defined as the ratio of the ideal isentropic compression power to the real compression power. Gas refrigerant injection has been proven effective for decreasing the under compression loss and improving the indicated efficiency of the scroll compressor under large SCR conditions (Winandy et al., 2002; Park et al., 2002; Ma et al., 2003; Beeton et al., 2003; Wang, et al., 2008). For small SCR conditions, the suction gas bypass technology is expected as a solution to decrease the over compression loss and enhance the inner compression efficiency (Shibamoto et al., 2003; Shin et al., 2005, 2008; Wang et al., 2012).

On the other side, the air conditioner always intends to work in small load ratio (equals to real capacity/rated capacity) conditions. That's because the real outdoor environment is much milder than the design working condition. Besides that, the rated capacity of the air conditioner is always much larger than the static cooling/heating load of the room because the air conditioner is selected according to the dynamic peak load of the room. For the air conditioner with on/off control, the system's start/stop loss during the build-up of the working condition is one of the most important factors affecting the energy performance.

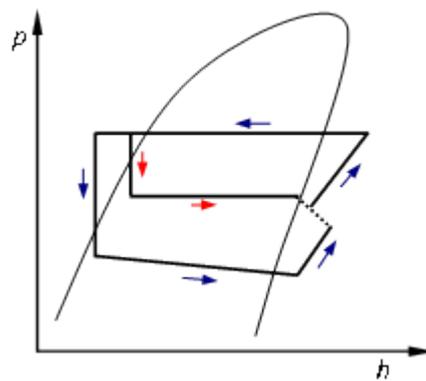
An air conditioner with DC/AC inverter compressor can turn the on/off control mode to the continuous capacity control mode and eliminate the start/stop loss. At the same time, the inverter control can increase the evaporating temperature, decrease the condensing temperature and eventually enhance the system energy performance. As results, the inverter technology has been widely applied in room air conditioners.

In this paper, an air conditioner combined inverter with ICR adjustment technology is proposed. The annual performance of proposed air conditioner is investigated by simulation and the performance is compared with the common inverter air conditioner. The potential of the ICR adjustment technology is revealed.

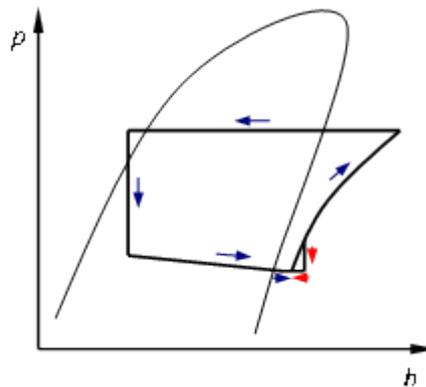
INVERTER AIR CONDITIONER WITH CONTINUOUS ICR ADJUSTMENT



(a) System schematic



(b) Refrigerant injection



(c) Refrigerant release

Figure 1 schematic and thermodynamic processes of inverter air conditioner with ICR adjustment

Figure 1 shows the schematic of the proposed inverter air conditioner with continuous ICR adjustment. The speed of the compressor can be modulated by an inverter according to the cooling load, continuously. The ICR can be continuously adjusted according to the SCR by gas injection and gas release. When the ICR is smaller than the SCR, the gas injection function is put in use. In Figure 1, the regulating valve 1 opens, the regulating valve 2 closes, and the controllable check valve is switched to flow-in mode. The opening of the regulating valve 1 is decided by the discharge pressure of the compressor. When the ICR is larger than the SCR, the gas release is functioned. At that time, the regulating valve 1 closes, the regulating valve 2 opens, and the controllable check valve is switched to flow-out mode. The opening of regulating valve 2 is decided by the discharge pressure of the compressor.

METHODOLOGY AND MODELING

Theoretically, the effect of ICR adjustment on the efficiency of compressor can be easily figured out by the

Figure 2. In the figure, when the system compression ratio ( $\varepsilon_{sys}$ ) equals to the fixed inner compression ratio of the compressor ( $\varepsilon_i = V_i^n$ ) With continuous ICR adjustment, the inner compression efficiency can stay about 1.0. With fixed ICR, the inner compression efficiency will largely decrease when the working condition isn't the design condition, especially for small SCR conditions.

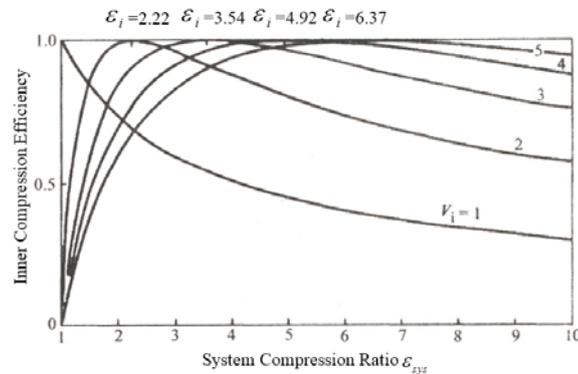


Figure 2 Variation of inner compression efficiency affecting by compression ratio

In this paper, we do not analyze the variation of inner compression efficiency under different working conditions. This research intends to bring out the general picture of how the mismatch of ICR and SCR affecting the seasonal energy consumption of IAC with scroll compressor, which can directly identify the engineering potential of ICR adjustment technology. According to this, numerical models of room, common IAC and IAC with continuous ICR adjustment are built up. The research work is conducted based on it. The research steps are: 1) construct typical rooms in different climate zones and calculate the cooling loads; 2) build up the models of the common IAC and IAC with continuous ICR adjustment; 3) simulate the energy consumption of common IAC and IAC with ICR adjustment hour by hour; 4) accumulate the seasonal energy consumption of IAC and IAC with ICR adjustment and compare them.

Two residential buildings located in Beijing and Shanghai of China are selected as the research targets. Two cities located in different climate zones are researched to identify the impact of climate on the conclusion. The parameters of envelope, equipment, and human of the buildings are set as the normal values according to the national architecture standards. In this research, the annual hourly load of typical buildings are calculated using building simulating software DeST, which is developed by Tsinghua University of China and has been validated by many lab experiments and field measurements.

For the IAC, the distributed parameter heat exchanger models are used in the simulation of the evaporator and condenser. Gnielinski correlation (Holman, 2011), Gungor-Winterton correlation (Gungor et al., 1987) and Dobson-Chato correlation (Dobson et al., 1998) are selected as calculation formulas of heat transfer coefficients of refrigerant in the single-phase zone, two-phase evaporating zone and two-phase condensing zone, respectively. Moddy correlation (Holman, 2011) and Friedel correlation (Didi et al., 2002) are used to calculate the pressure drop of refrigerant in tube. The expansion valve model is simplified into an isenthalpic equation by assigning a fixed superheated degree at the outlet of the evaporator. The mass conservation equation of the total refrigerant is replaced by the fixed subcooling degree at the outlet of the condenser. A previous proposed distributed-parameter model (Wang et al., 2006) is modified to simulate the inverter scroll compressor with fixed inner volume ratio. The system model is solved by the sequential module method (Ding et al., 2007). The whole model was validated by experiments in previous research (Wang et al., 2006).

For the model of IAC with ICR adjustment, the simulation process can be conducted following Figure 3. Firstly, the simple IAC is calculated for base ICR and SCR. When the SCR is larger than the ICR, the simulation model of air conditioner with gas injection is called and the injection pressure is changed to adjust the discharge pressure until the ICR equals to the SCR. When the SCR is smaller than the ICR, the simulation model of air conditioner with gas release is called and the release pressure is changed to adjust the discharge pressure until the ICR equals to the SCR. Finally, the energy performance is calculated. During the simulation, the frequency of the compressor is modulated according to the load.

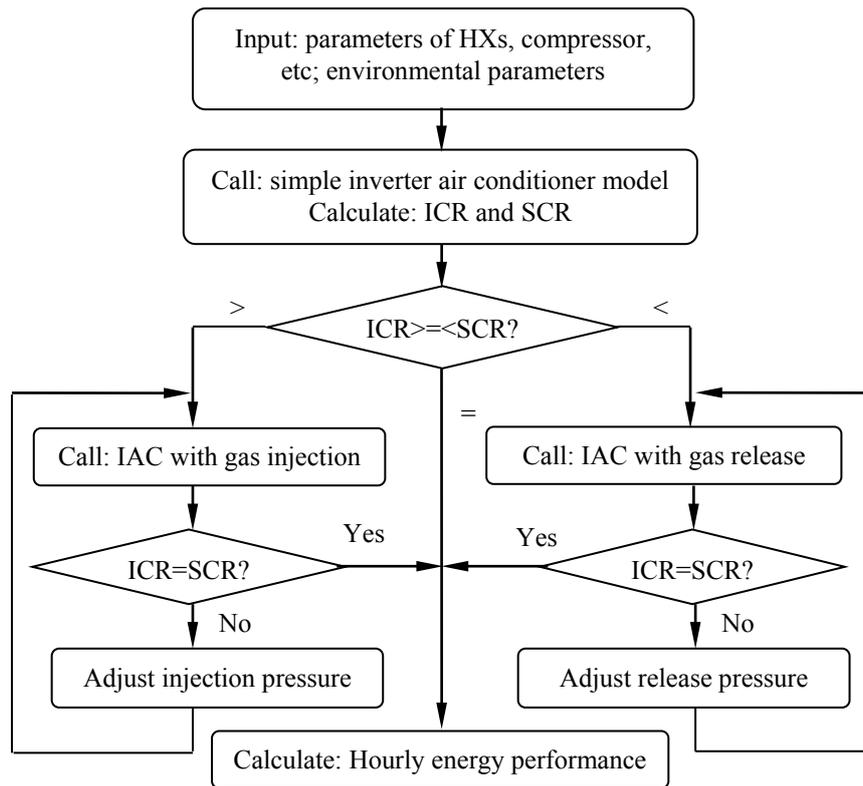
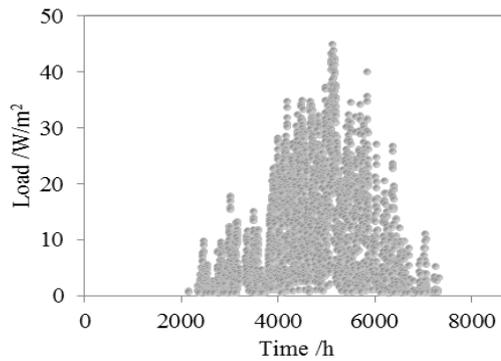


Figure 3 Simulation process of IAC with ICR adjustment

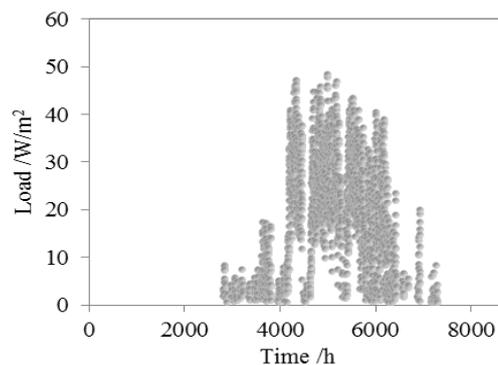
## RESULTS AND DISCUSSION

### Hourly load distributions

Figure 4 shows the hourly cooling load of the typical rooms in Beijing and Shanghai. For easy understanding, only the cooling season is showed in this paper.



(a) Beijing



(b) Shanghai

Figure 4 Cooling load of the typical buildings in different climate zones

Figure 5 shows the relationship between cooling load and the outdoor dry bulb temperature. It can be found that the cooling load of the residential building is close related with the outdoor temperature; the cooling load linearly decreases with the decrease of the outdoor dry bulb temperature; at most of the time, the load is lower than the load under rated condition (red point on the figure) because the working conditions are much more moderate than the rated condition. It means that the IAC will work in much small load ratio at most of the time and the use of inverter in air conditioner will largely decrease the times of start/stop, increase the evaporating pressure, decrease the condensing pressure, and finally enhance COP of the air conditioner.

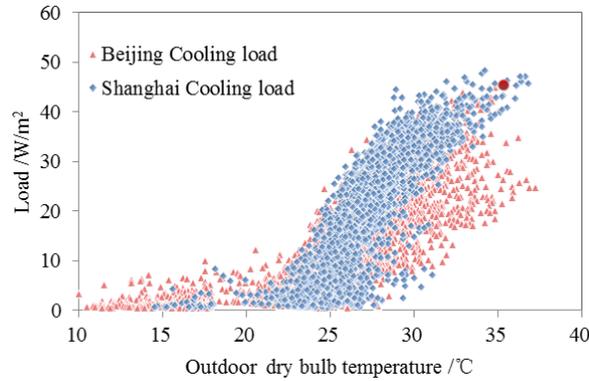
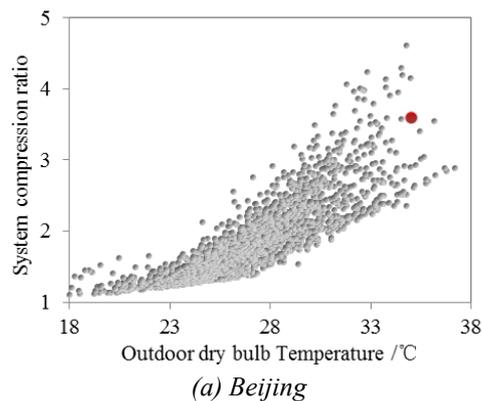


Figure 5 Variation of cooling load with outdoor dry bulb temperature

### System compression ratio (SCR)

Using the simulation model of IAC, the refrigerant states and performance can be obtained. Before considering the energy performance, the SCR is analyzed firstly. Because the SCR is decided by the indoor temperature, outdoor temperature, heat transfer temperature difference of evaporator and condenser, which relies on the indoor load of the room, the SCR is more like an environmental and room parameter and is not related with the performance of the compressor.

Figure 6 illuminates the variation of SCR along with the outdoor temperature. It can be found that the SCR also largely decreases with the decrease of the outdoor temperature, like the cooling load; the real SCR is much smaller than the SCR under the rated condition (red point on the figure); the decreasing slope of SCR is larger than the decreasing slope of the cooling load, which can be attributed to the decrease of both the outdoor temperature and the temperature difference during heat exchange.



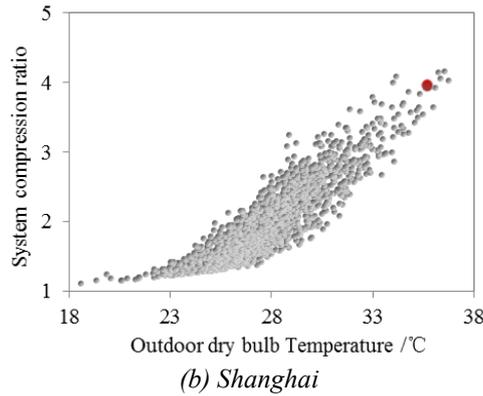


Figure 6 Variation of system compression ratio with the outdoor dry bulb temperature

Combined Figure 6 and Figure 2, it can be found the inverter air conditioner is more often working in under-compression conditions and the compressor efficiency are heavily affected by the inner compression efficiency.

Figure 7 shows the relationship between SCR and load ratio. The SCR is closely exponentially related with the load ratio. So the ideal air conditioner needs to have the ability to modulate both capacity and ICR to small value for high seasonal energy performance.

### Energy consumption

The energy consumptions by the IAC and the IAC with ICR adjustment can be calculated by the previously proposed models. The hourly power consumptions are presented in Figure 8. It can be concluded that the implement of technology of ICR adjustment, such as refrigerant release, can obviously decrease the power consumption of the air conditioner, especially for the small load ratio conditions.

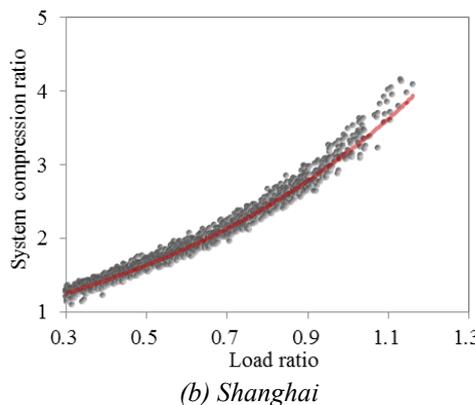
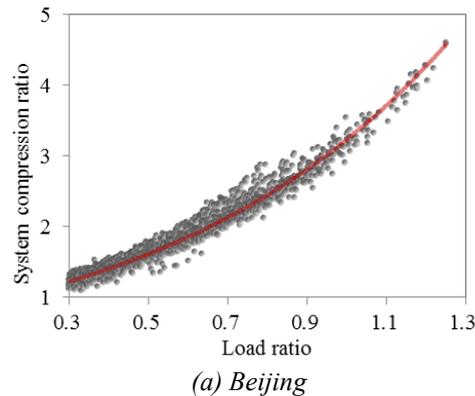
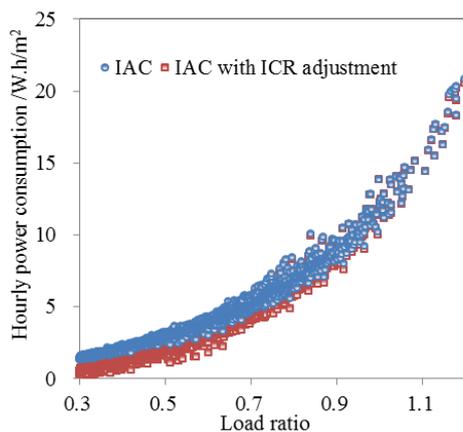
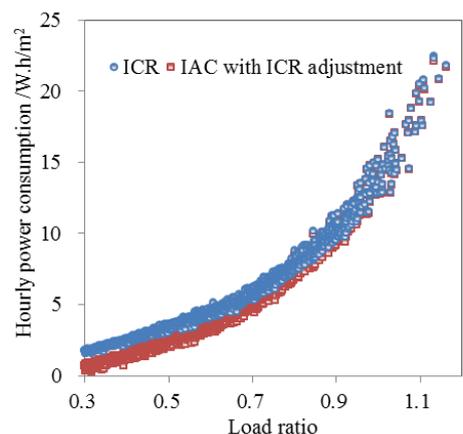


Figure 7 Variation of system compression ratio along with the load ratio

For scroll compressors with different inner volume ratio, the implement of technology of ICR adjustment on the performance of the compressor and air conditioner should be different. The total energy-saving potentials for different compressors are presented in Figure 9. It can be found that the ICR adjustment is more effective for compressor with large inner volume ratio and ICR adjustment can realize 10%~25% energy saving for IAC.



(a) Beijing



(b) Shanghai

Figure 8 Hourly power consumption of the common IAC and IAC with ICR adjustment

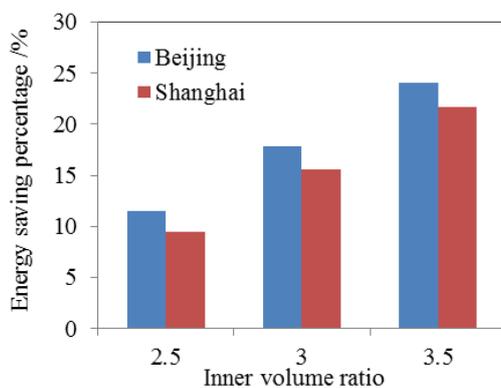


Figure 9 Energy saving potential of ICR adjustment

This paper just analyzes the energy-saving potential of ICR adjustment on the inverter air conditioner, the adaptability of this technology on the fixed speed air conditioner should be different and it will be researched in the future.

## CONCLUSION

The inherent feature of fixed inner volume ratio of scroll compressor causes large degradation of the compressor indicated efficiency when the inner compression ratio mismatches with the system compression ratio under off-design condition. The inner compression ratio adjustment technology, such as refrigerant injection and refrigerant release, can enhance the seasonal efficiency of the compressor and the air conditioner. Through a seasonal simulation, some conclusions can be made:

1) The real operating cooling load of the residential building is much smaller than the design cooling load under the rated condition;

- 2) The room air conditioner needs to work in much small system compression ratio conditions at most of the time;
- 3) The implement of technology of ICR adjustment, such as refrigerant release, can obviously decrease the power consumption of the air conditioner, and realize 10%~25% energy saving on the IAC.

### ACKNOWLEDGEMENT

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