Overview of the Development of the SRK_23S Series of Residential Air Conditioners with Improved Heating Capacity to Achieve Carbon Neutrality

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Attention has been focused on heating with a heat pump (HP) as a major technology to achieve carbon neutrality (CN), because such HPs emit a smaller amount of greenhouse gases than fossil fuel combustion heaters. However, further improvement in the efficiency of HP heating is also required to reduce CO_2 emissions from power consumption, in addition to shoring up a weak point due to its characteristics, that is, the capacity when the outdoor air temperature is low.

The recent housing situation is increasing the number of cases in which residential air conditioner is installed to cool/heat a living-and-dining-combined space of 20 tatami mats (approximately 36.48m^2) or more, resulting in a rise in the need for large-capacity air conditioners. Under such circumstances, Mitsubishi Heavy Industries Thermal Systems, Ltd. added newly developed room air conditioners for 2023 to its product lineup. These include the air conditioners with cooling capacity of 6.3, 7.1 and 8.0kW for living rooms with the realization of a 13% energy saving performance improvement compared with the existing models, and the new models for cold climates with a substantial capacity improvement at low outdoor air temperatures.

1. Introduction

Heating with an HP has been of interest as a major technology to achieve CN. However, when it comes to heating capacity, fossil fuel combustion heaters are generally superior and therefore, HP heating with high capacity is essential in facilitating the replacement of the heaters. As the temporal change in energy consumption by use per household indicates that air conditioning accounts for about 30% of the energy consumption at home[(1)], the target levels by the Energy Efficiency Standards for Home Air Conditioners were strictly reviewed in 2022 by the Japanese government in order to reduce the CO_2 emissions from energy consumption and promote CN. The new deadline was set at 2027. Let us give an example of the models for 14 tatami mats (a space of approximately 25.54m^2) with a cooling capacity of 4.0kW. Their annual performance factor (APF), which shows year-round energy consumption efficiency and is used as an Energy Efficiency Standards goal indicator, was substantially raised from the current 4.9 to 6.6. If air conditioners fail to comply by 2027, the new standards are strict enough to ban their sale. In recent Japanese housing, there is an increasing number of cases in which a single air conditioner unit is installed to cool/heat a combined living-and-dining space of 20 tatami mats (approximately 36.48m^2) or more, thereby increasing the need for air conditioners to have a cooling capacity as large as 6.3kW (for a space of 20 tatami mats) at the least. Given such circumstances, we have successfully met the levels prescribed by the New Energy Efficiency Standards way ahead of the deadline of 2027. This report summarizes the technologies used in developing these new 23S series of room air conditioners for 2023, which are characterized by a large capacity fit for use in a living room and a high heating capacity.

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2. Improved energy saving performance, high heating capacity and large capacity

In the 23S series, a 13% improvement in energy saving performance has been achieved by the 4.0kW model, with an APF of 7.0 compared to 6.2 for the existing model (SRK4022S2). This means an 11% reduction in annual power consumption (comparing 1,220kWh of SRK4022S2 to 1,081kWh of SRK4023S2). When converted to the reduction effect on greenhouse gas emissions over an average air-conditioner life of 13.7 years, it is estimated to be about 1.3 tonnes of CO_2 equivalent, which is a substantial sum. The low-temperature heating capacity, which is defined as the heating capacity at an outdoor air temperature of 2°C, is 8.8kW and has been improved by 31% compared to 6.7kW for the existing model (SRK4022S2). Furthermore, the 6.3, 7.1 and 8.0kW large-capacity classes, which were not available in the existing series, have been added to the product lineup. This chapter describes each component developed in order to achieve these improvements.

2.1 Improvement of air blower system performance

Each of the indoor and outdoor units of a room air conditioner is equipped with a blower motor. Since the total power consumption of the blower motors accounts for nearly 15% of the power consumed by the room air conditioner as a whole, the improvement of air blower systems that can reduce power consumption also contributes to improving the APF.

In this development, computational fluid dynamics (CFD) analysis was performed on both indoor and outdoor units, to optimize the shape of the blower fan, heat exchanger configuration, and air flow path. As a result, including the use of a high-efficiency motor, the power consumption of the blower fan has been reduced by about 30% in the indoor unit and about 40% in the outdoor unit, when compared with the existing models. **Figure 1** shows a CFD analysis result for the indoor unit.

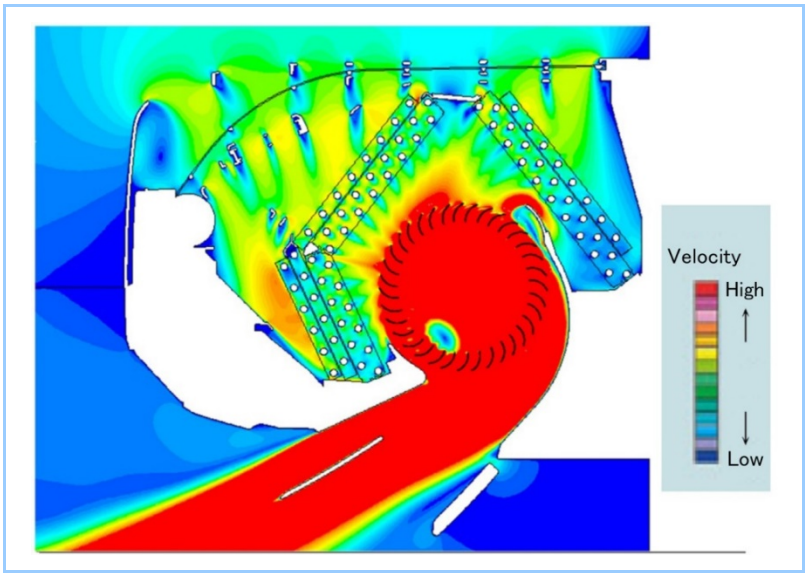

Figure 1 Optimize air blower system design using CFD analysis

2.2 Larger-capacity and higher-efficiency compressor

In the 23S series, a new twin rotary compressor with a capacity increase to 15cc from the existing 13cc has been developed in order to improve not only the APF but also the capacity of room air conditioners. To realize a higher APF, it is necessary to improve the compressor, which is responsible for most of the power consumed by the air conditioner. However, an increase in the mechanical loss becomes an issue as the compressor capacity gets larger. We have therefore improved the losses caused in the compression mechanism and the compressor motor. In the compression mechanism, the loss due to blade sliding friction grows, as the increased capacity increases the stroke (**Figure 2**). As a solution, diamond-like carbon (DLC) coating was applied. DLC is a hard thin film made of carbon and formed on the surface of a part. A lower coefficient of friction results in less friction loss, enhancing the resistance to wear. Thus, the friction loss due to

blade sliding is reduced, while the reliability is improved.

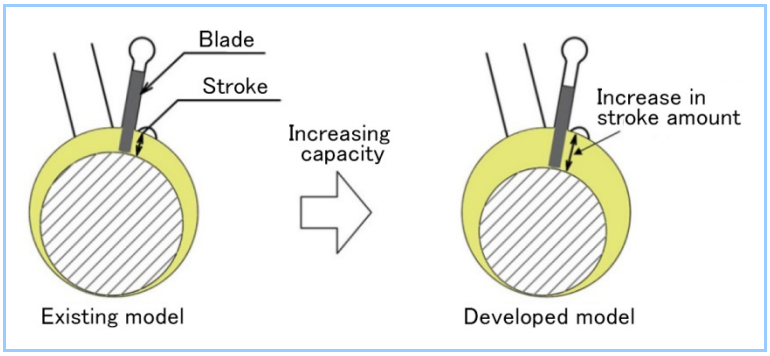

Figure 2 Area in which blade sliding loss is increased

For the compressor motor, the increased number of copper windings (i.e., a high number of turns) and high-grade neodymium magnets were employed to secure the necessary power using a smaller electric current than the previous models. The motor stator of our compressor is shrink-fitted to the housing, which causes deformation in the motor stator and may increase the motor loss. In our compressor, however, the shape of the motor stator was designed in such a way as to be the small deformation by shrink-fitting, thereby reducing the loss. **Figure 3** shows the analysis result of motor stator deformation by shrink-fitting, which indicates that the stress concentration areas are smaller than the existing models. Augmented by other improvements as well, our new compressor has achieved 5% higher efficiency than the existing 13cc compressor.

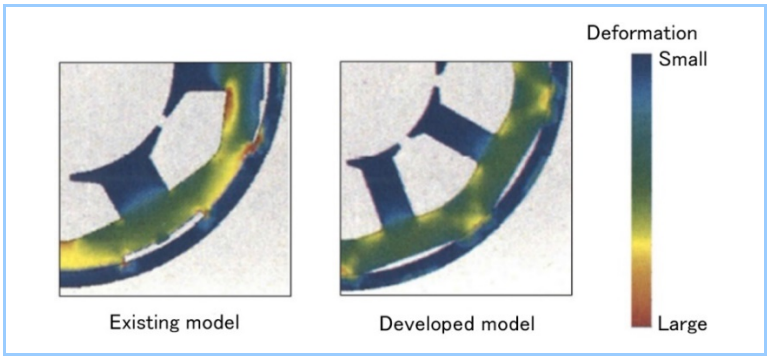

Figure 3 Compressive stress in motor stator

2.3 Improvement of inverter performance

For realizing higher efficiency, the inverter that drives the compressor has a circuit configuration as shown in **Figure 4**. The major changes from the existing models include the adoption of a bridgeless converter with a PAM (pulse amplitude modulation) control circuit, a high-efficiency reactor, and superjunction MOS-FETs (metal-oxide-semiconductor-field-effect transistors).

In the AC/DC converter circuit, AC from the power source is smoothed out to DC. The loss due to forward voltage of diodes has been reduced by adopting diode bridgeless rectification instead of the conventional diode bridge rectification, especially making it a bridgeless converter with a PAM control circuit. Moreover, superjunction MOS-FETs are used as the switching element, whereby the switching loss is reduced. The loss due to voltage drop caused by parasitic diodes in superjunction MOS-FETs has also been reduced by simultaneously performing synchronous rectification control. A low-loss reactor has been employed by re-examining the core material to reduce the iron loss.

In high boost control of DC (Direct Current) voltage, we have developed and introduced a new algorithm to control in such a way as to minimize the sum of converter loss, inverter loss and motor loss by adjusting the boosted level of DC voltage and the output voltage waveform of inverter vector control according to the motor operation conditions in combination with the inverter control.

In the inverter circuit, a superjunction MOS-FET module is employed instead of the IGBT

(Insulated Gate Bipolar Transistor) module used in the previous models. This makes it possible to substantially reduce the switching loss and the conduction loss, thus greatly contributing to better inverter efficiency. Moreover, expanding the over-modulation range of inverter vector control reduces the motor current distortion at high-speed revolutions, which is a disadvantage of motors with a high number of turns. Thus, the iron loss in the compressor motor has been reduced, while the operable range has been expanded together with realizing a higher heating capacity.

The other adoptions for higher efficiency include high-efficiency elements, technology to lower the loss in switching power supply circuits, low power consumption CPUs (Central Processing Units), and low-loss noise filter circuits. The further addition of the above-mentioned new technologies has reduced the controller loss by about 60% compared with the existing models.

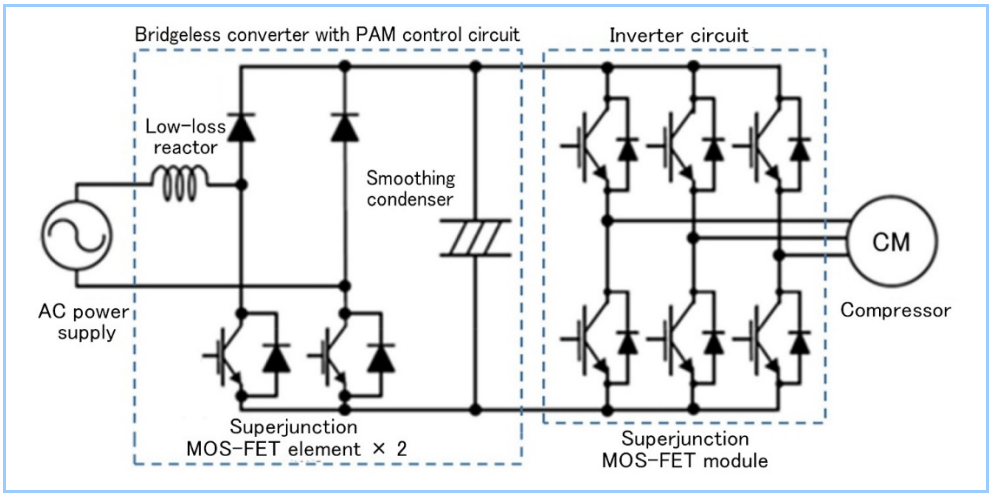

Figure 4 Configuration of outdoor unit controller circuit

2.4 Performance improvement as air conditioner

If optimized performance as an air conditioner is to be achieved, the efficiency as a system needs to be maximized through appropriate adjustment of the factors such as the number of compressor revolutions, and the volume of air flow into the inside/outside of the room. This should be done by combining each of the elements described in sections 2.1 to 2.3. With regard to the indoor unit heat exchanger, the optimal system operation point has been realized by ramping up the heat exchange capacity with a multi-row configuration. For the outdoor unit heat exchanger, large capacity performance has been secured by preventing the refrigerant pressure loss, which is a setback to the performance at the maximum capacity, through adopting a smaller-diameter copper tube than the existing models and making the refrigerant flow path a multi-branched configuration.

Moreover, in an attempt to improve the heating capacity at low temperatures, we have enabled the following: increased compressor capacity, improved inverter performance, and optimal control of both defrosting operation and heating start-up after a defrosting operation. Improved low-temperature heating capacity has been thus realized.

2.5 Development of air conditioners for cold climates

In cold climates, the use of fossil fuel combustion heaters still dominates. Air conditioners for cold climates have also been developed with a view to facilitating the transition or substituting to HP heating, and are characterized by the improved low-temperature heating capacity for each of the capacity ranges. For example, in the 4.0kW class model for cold climates, the low-temperature heating capacity has been enhanced to 8.9kW, while it is equipped with a defrosting operation function using a hot gas bypass method by which an indoor temperature drop can be prevented even during defrosting operation. Moreover, a heater to prevent the freezing of water discharged after defrosting is installed at the bottom of the outdoor unit heat exchanger. The outdoor unit is also provided with fan control, by which air is blown on a regular basis to prevent the outdoor unit's air flow path from being snowed up when the air conditioner is not in operation. A superior heating capacity making it operable at an outside air temperature of -25°C has thus been realized. The cold climate models with these functions, which have been added to our product lineup, are expected to facilitate the replacement of combustion heaters with HP heating and help to realize CN.

3. Environmentally responsible design

In developing the 23S series, besides improving energy saving performance, we are actively promoting the introduction of energy-saving functions, resources conservation, and use of recycled resources as part of our environmental conservation initiative. Described below are the major environmentally responsible design technologies.

3.1 Lightweight compressor

While the compressor's motor efficiency has been improved as described in section 2.3, the steel plate of the motor has also been reduced in thickness. The motor weight is thus lighter by about 20% from the existing compressor models. When it comes to the casing of the compressor, the weight has been cut by about 40% by reducing the plate thickness and the height of the compressor to conserve resources. Furthermore, the improved lubrication system in the compressor has enabled the refrigeration oil to be 20% less in quantity. As a result of these improvements, the compressor as a whole has been reduced in weight by about 20%.

3.2 Use of used tea leaves-recycled resin

Used tea leaves were once discarded as waste. However, ITOEN, Ltd. has built its own recycling system for their effective use as various materials. As part of this project, "the used tea leaves-incorporated resin" has been developed. As part of our efforts to effectively utilize recycled resources, we employed this used tea leaves-incorporated resin as the holder of the air-cleaning filter, which is environmentally friendly, for the 23S series as well (**Figure 5**).

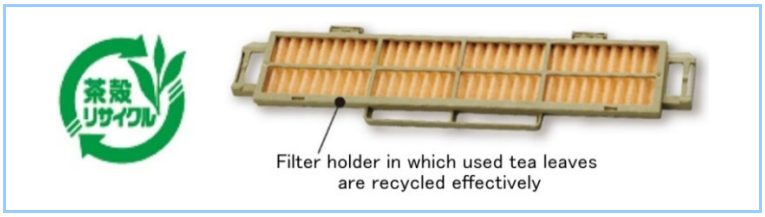

Figure 5 Filter holder in which used tea leaves are recycled

3.3 Reduced amount of refrigerant

The use of a small-diameter tube heat exchanger in the indoor/outdoor units has reduced the amount of refrigerant by 11% from the conventional level (comparison between 1,350g for SRK4022S2 and 1,200g for SRK4023S2). The refrigerant R32, which is used in our new air conditioners, has a global warming potential (GWP) of 675. When converted to the reduction effect on greenhouse gas emissions per air conditioner, it is estimated to be about 100kg of CO_2 equivalent. It can therefore be expected to have a considerable effect on reducing greenhouse gas emissions.

3.4 AI automatic operation for comfort

The 23S series are our first air conditioners that have been equipped with an "AI function" for reducing power consumption. With regard to a room in which an air conditioner is installed, AI detects how easily the room can be cooled/heated and automatically adjusts the operation capacity when air conditioning is started, thereby allowing no power to be consumed unnecessarily. The results obtained in our environmental test laboratory indicate that the use of AI control produces approximately an 8% reduction in power consumption (please note that the actual effect may vary depending on the user's room conditions such as thermal insulation performance).

3.5 Automatic filter cleaning function

As in the existing models, our new air conditioners are equipped with an automatic filter cleaning function that reduces the time and work required to clean the indoor unit filter. Based on how an air conditioner is operated, the filter is automatically cleaned at appropriate intervals to cause less dust to clog the filter. This can reduce the airflow energy loss in air conditioners, enhancing energy saving performance.

3.6 Set temperature in 0.5°C units

The set temperature by the remote control, which can be controlled in 1°C units in the existing models, has been changed to 0.5°C. Enabling such fine-tuned setting makes it possible to create a comfortable environment without unnecessary power consumption.

4. Functions for better comfort

In purchasing an air conditioner, people value not only the price and basic performance, but also the "availability of additional functions" such as comfort and cleanliness. Described below are the additional functions newly added to the 23S series.

4.1 Dual sensor function (pyroelectric sensor + thermopile sensor)

While a pyroelectric sensor, which can detect the degree of human activity based on the change in the amount of infrared rays, is applied as in the existing models, the 23S series are also equipped with a thermopile sensor that can detect where the source of heat is by directly measuring the amount of infrared rays. In the new function, these sensors are used with technologies that detect the position of peoples, enabling air flow to be directed at them or be diverted from them. Others include air conditioning in accordance with the degree of activity, the moderating operation by which the operation capacity is automatically moderated when no one is in the room, and the auto-off function by which the operation is automatically turned off if the room remains unoccupied for a while. Thus, no power is consumed unnecessarily.

4.2 Dual ion function (freshening ion + aqua ozone)

Two ionizers are installed, one for the living space and the other for the inside of the indoor unit of an air conditioner. Our new series can provide the following modes: the "freshening ion mode" in which negative ions are released into the living to prevent viruses, bacteria and mold, the "aqua ozone clean mode" in which the inside of the indoor unit is filled with ions and ozone to prevent the proliferation of causative microorganisms for odor and uncleanliness, and "aqua ozone heating operation" in which the heat exchanger is heated/dried by heating operation to prevent the proliferation of mold.

4.3 Wireless LAN function

Equipped with a wireless LAN interface as standard, our new series can be remotely operated from a smartphone. Moreover, by linking with a smart speaker, it becomes possible to voice-control the air conditioner and check the operation conditions. Thus, the operability has been further improved (usable with Google Assistant and Amazon Alexa).

5. Conclusion

As a high-end air conditioner for 2023, the 4.0kW model has achieved an APF of 7.0. This was enabled by the reduced power for blowers in the indoor/outdoor units and the new development and adoption of a high-efficiency compressor and an inverter. When the reduced amount of refrigerant is converted to the reduction effect on greenhouse gas emissions per air conditioner, it is estimated to be about 100kg of CO_2 equivalent. When it comes to the effect resulting from the reduced power consumption by the air conditioner, it is about 1.3 tonnes of CO_2 equivalent. In total, it becomes about 1.4 tonnes of CO_2 equivalent. This can be expected to have a considerable effect on reducing greenhouse gas emissions. There are also other effects as well. These included the following: improved energy saving performance during normal operation using the AI, dual sensor, and automatic filter cleaning functions; environmentally responsible design for resources conservation and use of recycled resources; and improved low-temperature heating capacity promoting the replacement of combustion heaters. Our new products can be expected to make a substantial contribution toward the achievement of CN.

The nine 2.2 to 8.0kW models of 23S series for 2023, which were developed with a view to helping realize CN, will start mass production in March 2023. The four 2.5 to 5.6kW models of 23SK series for cold climates, which are based on the 23S series with the addition of a hot gas bypass defrosting function, have also been added to our product lineup to promote early replacement of combustion heaters.

From next year and beyond, we will continue to develop products with low environmental impact that can contribute to early achievement of CN.

References

(1) Energy-Saving Efficiency Performance 2022, Agency for Natural Resources and Energy, Ministry of Economy, Trade and Industry