Development of Multi Air Conditioners for Skyscrapers with Greatly Expanded Installation Flexibility

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Mitsubishi Heavy Industries, Ltd. (MHI) has introduced the new KXE6 high-head air conditioner series to its product line to meet the market need for highly efficient skyscraper units. This joins the export model KXE6 multi air conditioner series designed for conventional buildings. A feature of this product is that the maximum vertical distance between the outdoor unit on the roof and the indoor units has been increased substantially to 90 m (100 m for coolers), compared to 50 m for conventional units. This report describes the technology used to extend the vertical distance for installation of the KXE6 series.

1. Introduction

Customer requirements for air conditioners have become increasingly diverse, and installation flexibility as a selection criterion is as important as reliability and high efficiency. Skyscraper designers and owners, in particular, demand a greater vertical distance between the outdoor and indoor units of multi air conditioners. We have developed a very reliable product to meet this need through analyses using our proprietary PRANET software and testing in our building in Yokohama. This report describes the product features of multi air conditioners for skyscrapers, which permit a substantially increased vertical distance between the indoor and outdoor units.

2. Features and Specifications of Multi Air Conditioners for Skyscrapers

Figure 1 shows the vertical distance limit for our new skyscraper multi air conditioners.

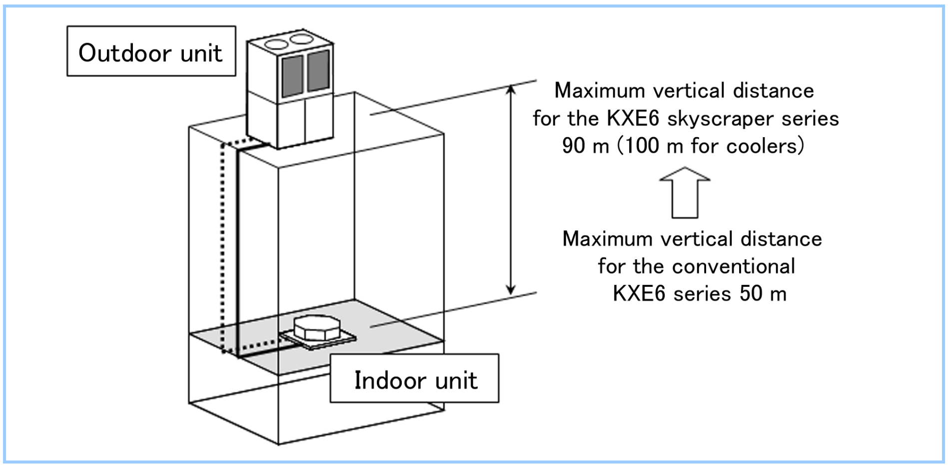

Figure 1 Vertical limit specifications for installation of the KXE6 skyscraper series
The maximum vertical distance is much greater than for the conventional KXE6 series.

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The maximum distance between the indoor and outdoor units has been significantly increased to 90 m (100 m for coolers) from the conventional distance of 50 m. A conventional system installed in a building taller than 50 m requires outdoor units in mid-building. With our new product, however, the outdoor units can be placed on the roof to provide greater flexibility in system design. The unit size of the KXE6 skyscraper series remains the same as the conventional KXE6 series, as the hardware changes made for the new series have been installed successfully without the need for extra space.

3. Technology for the Extension of the Vertical Distance

The development of multi air conditioners for skyscrapers encountered the following technical challenges, caused by pressure in the pipe for either the gas refrigerant (gas pipe) or liquid refrigerant (liquid pipe) resulting from the change in hydraulic head when the vertical distance between the outdoor and indoor units exceeds 50 m (high-head condition):

(1) retention of refrigerant oil in the compressor,

(2) mitigation of performance reduction due to an increased pressure drop in the liquid pipe during heating, and

(3) reduction of the liquid head pressure in the indoor unit during cooling.

To deal with these technical challenges, we conducted tests with an actual 85-m vertical distance in the Mitsubishi Juko Yokohama Building. In a preliminary study, the *program for transient analysis using a node/link network* (PRANET) software package was used to estimate operational control conditions and assess the risks under the high-head condition. PRANET is a reliable dynamic simulation program that has been used to analyze the dynamic characteristics of rocket engine combustors, oxygen systems, and power plants. In multi air conditioners for buildings, it can deal with fluid temperature or pressure flow characteristics of the refrigerant or air, and can be used to study special usage environments, such as that related to the high-head condition.

3.1 Retention of refrigerant oil in the compressor

The refrigerant oil discharged from the compressor circulates during operation and remains in the air conditioner's refrigerant system, consisting of the piping network, heat exchanger, and other components. The outdoor unit is equipped with a separator to remove the lubricating oil from the refrigerant gas in a process that is less than 100% efficient. The refrigerant oil that is discharged into the refrigerant system must therefore be collected regularly. In the conventional KXE6 series, the refrigerant oil is collected during the cooling cycle by temporarily opening the indoor unit expansion valve as designed for this purpose, and letting the liquid refrigerant pass through the gas pipe and carry the refrigerant oil along with it to the outdoor unit. However, when the outdoor unit is installed at a distance greater than 50 m above the indoor unit, a large pressure drop in the pipe during refrigerant oil collection disturbs the liquid refrigerant return flow to the outdoor unit and makes collection of refrigerant oil difficult.

In developing the KXE6 skyscraper series, we examined control of the indoor unit expansion valve during refrigerant oil collection. During collection, the setting of this valve has to be determined to provide the appropriate amount of refrigerant oil and liquid refrigerant returning to the outdoor unit. A test of refrigerant oil collection was conducted in the Mitsubishi Juko Yokohama Building, with an 85-m vertical distance between the outdoor and indoor units, to determine the optimum control of the indoor unit expansion valve.

Figure 2 shows the relationship between the opening of the indoor expansion valve and the rate of refrigerant oil collected using actual units during the test at the Mitsubishi Juko Yokohama Building. Under such conditions in the conventional KXE6 series, the 85-m vertical interval produced a large pressure drop in the pipe during refrigerant oil collection and disturbed the liquid refrigerant return flow to the outdoor unit. The oil collection rate throughout the oil collection operation was zero. In sharp contrast, under the same conditions using the KXE6 skyscraper series, as the indoor expansion valve was further open, the liquid refrigerant returned steadily to the outdoor unit achieving a 100% oil collection rate. The liquid refrigerant did not re-enter the outdoor unit excessively during refrigerant oil collection.

In the KXE6 skyscraper series, the optimum operating point for refrigerant oil collection was determined based on the results of the tests conducted with an actual vertical interval, and shortage of refrigerant oil in the compressor, even under high-head conditions, was substantially reduced.

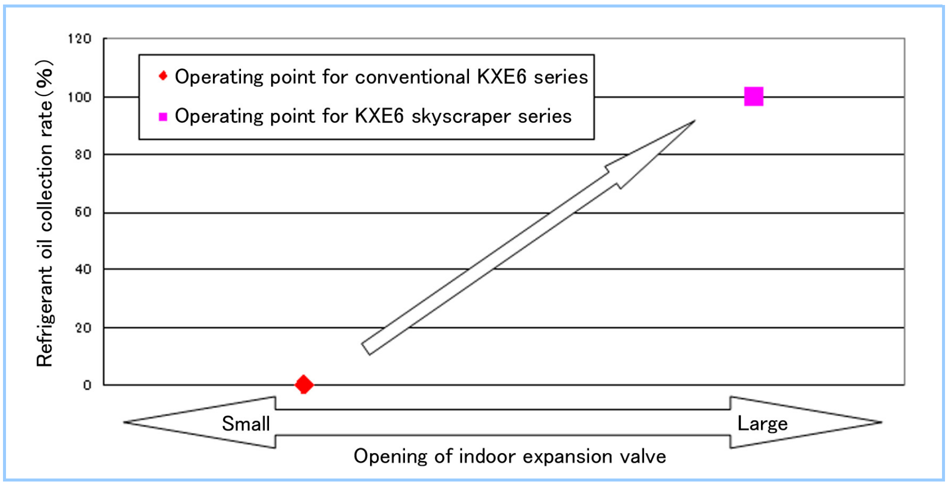

Figure 2 Relationship between the oil collection rate and the opening of the indoor unit expansion valve during refrigerant oil collection
The operating point of the KXE6 skyscraper series, in which the opening of the indoor expansion valve is greater than in the conventional series, results in an oil collection rate of 100%.

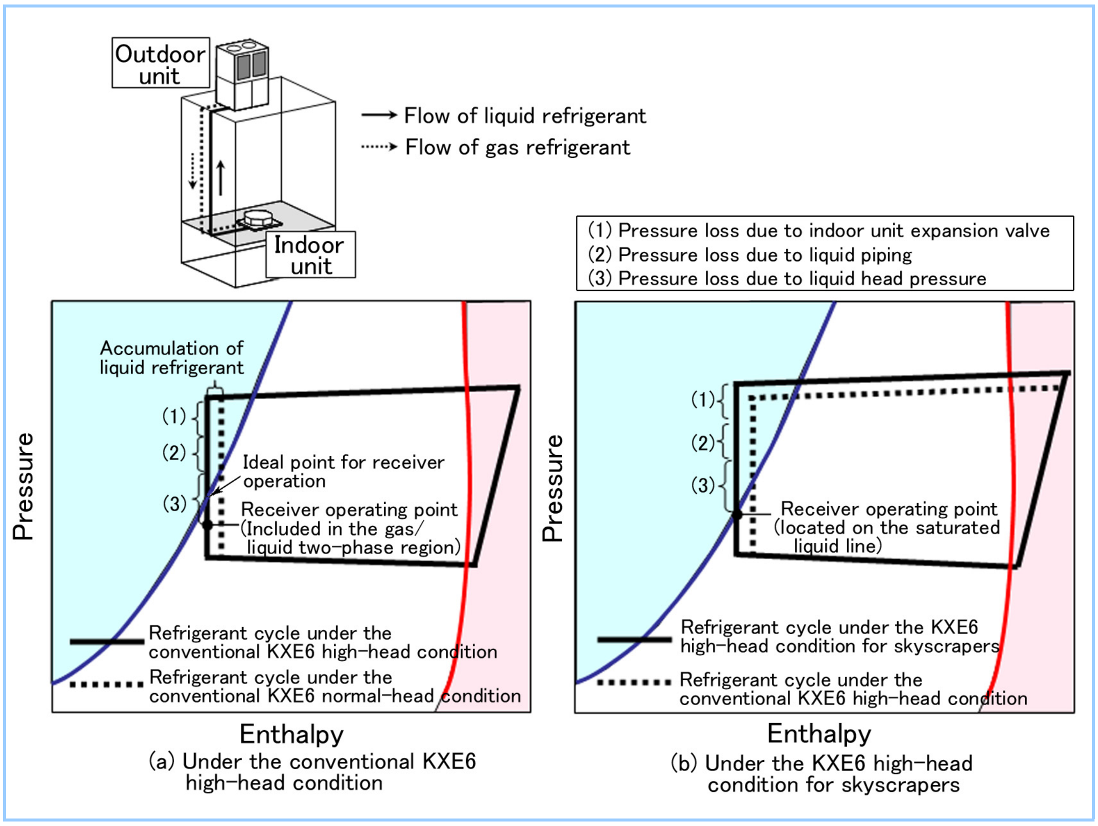

Figure 3 Mollier diagram showing refrigerant-cycle examples during heating under the high-head condition, with the outdoor unit installed higher than the indoor unit
Heating operation under the high-head condition may create a two-phase gas/liquid state in the receiver because of a pressure drop due to the applied liquid head pressure. The operating point for skyscraper units, however, allows the receiver to operate at a saturated liquid state, enabling excessive refrigerant to be controlled.

3.2 Mitigation of performance reduction due to an increased pressure drop in the liquid pipe during heating

A receiver is located in the refrigerant circuit of the KXE6 series system. It temporarily stores the liquid refrigerant that has been liquefied by the condenser, and is set to operate at a certain condition that can be plotted on the saturated liquid line in a Mollier diagram. **Figure 3** shows refrigerant-cycle examples on a Mollier diagram under the high-head condition during heating. One of the biggest changes caused by the high-head condition is the increase of pressure drop in the liquid pipe due to the applied liquid head pressure. As shown in Figure 3(a), an increased pressure drop in the liquid pipe can create a two-phase gas/liquid state in the receiver, and the receiver can no longer control the excess amount of refrigerant. This excess collects as liquid refrigerant in the indoor unit that is upstream from the receiver in the refrigerant circuit and may cause inadequate heating performance.

In the development of this product, we dealt with this issue by reviewing the high-pressure control target level and the set point for supercooling required to create a saturated liquid state in the receiver during heating. The set point was initially estimated using PRANET, and the exact value was determined later based on the results of the confirmation tests using actual air conditioning units.

The set point change, based on the PRANET calculation, enabled control of the excess refrigerant and undisturbed performance under the high-head condition. In subsequent tests with the actual units, the exact value of the set point estimated in the analysis was confirmed experimentally, which led to determining the appropriate amount of refrigerant required for supercooling in the KXE6 skyscraper series.

These test results indicate that the KXE6 skyscraper series of air conditioners are capable of adequate heating performance even under the high-head condition.

3.3 Reduction of the liquid head pressure in the indoor unit during cooling

Based on the PRANET analysis, **Figure 4** shows refrigerant cycle examples on a Mollier diagram during cooling with the outdoor unit installed higher than the indoor unit. Extra liquid head pressure is present in the liquid pipe under the high-head condition.

To counter this, a new system was installed in the outdoor unit to decrease the pressure in the liquid pipe. It controls the refrigerant by reducing the pressure to the desired level in the outdoor unit and preventing the buildup of excessive pressure on the indoor unit expansion valve. Through a test using actual air conditioning units, the operating point of the pressure-reducing system for the liquid pipe was optimized to reduce the pressure to the desired level within vertical separations of 50–90 m (50–100 m for coolers).

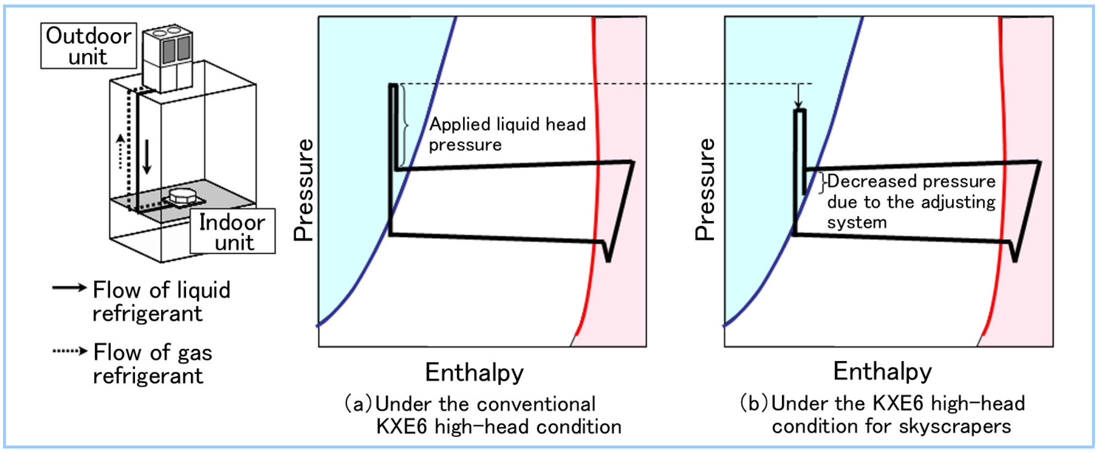

Figure 4 Mollier diagram showing refrigerant cycle examples during cooling under the high-head condition with the outdoor unit installed higher than the indoor unit
Liquid head pressure is applied during operation under the high-head condition. The KXE6 skyscraper series includes an adjusting system to prevent the application of excessive pressure on the indoor unit.

4. Conclusion

We have significantly increased the installation flexibility of multi air conditioners for buildings by increasing the maximum vertical distance between the indoor and outdoor units. We have also demonstrated that PRANET is a useful tool for improving the quality and reducing the development time of multi air conditioners for buildings in which live testing is difficult to conduct. We will continue to meet our customers' evolving demands in the global marketplace for multi air conditioners by increasing installation flexibility even further.

Reference

1. Akazawa et al., Development of Packaged Air Conditioners Applying to Many Using Environments ,Mitsubishi Juko giho Vol.41 No.2 (2004) pp. 82-85