Development of Air-to-Water Heat Pump for Home Air conditioning/Hot Water Supply Combination System with Chilled/Hot Water in European Markets
- Extending Use of New Heat Pump System in Cold Regions -

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With European heat pump manufacturer NIBE Industrier, Mitsubishi Heavy Industries, Ltd. (MHI) has jointly developed an air conditioning/hot water supply combination system with chilled/hot water suited for European domestic use. As part of the joint development, a mutual OEM supply system was established; the outdoor unit was developed and supplied by MHI based on conventional air conditioner technologies and the indoor unit was supplied by NIBE. Hot water supply systems utilizing heat pump technology are products that are attracting attention in European heating markets, because drastic reductions in CO_2 emissions and running costs can be attained compared with conventional boiler systems. The system allows the practical application of heat pumps in cold regions such as northern Europe by introducing an advanced refrigerant control system that realizes a hot water discharge temperature of 58°C even at an ambient temperature of -20°C.

1. Introduction

In Europe, the basic style of domestic heating is whole-building and around-the-clock heating where hot water produced by a heat source unit is re-circulated to heat dissipation appliances such as radiators, which is different from the Japanese heating style. Natural gas and other fossil fuel-fired boilers have been the mainstream heat sources.

Due to increases in the prices of crude oil and natural gas, the risk of ensuring a supply of natural gas and the recent upsurge in concern about environmental issues, however, new heat source units that have the potential to reduce CO_2 emissions by utilizing an electric heat pump system are in the spotlight.

As such, with European heat pump manufacturer NIBE, MHI has jointly developed a chilled/hot water supply system for air conditioning and hot water supply appliances based on conventional air conditioning systems (air to water heat pump). This paper introduces an overview and the features of the air to water heat pump for European domestic use.

2. Overview of Product System

Figure 1 shows an overview of a system using this product. Hot water pipes for heating and hot water supply are connected to the indoor unit.

The unit can use fan coils and radiators as the heat dissipation appliances, which require relatively high temperature water discharge, as well as floor heating appliances that use low temperature water discharge. It can be controlled for either appliance or for several appliances simultaneously requiring different water temperatures. In addition, the chilled/hot water system for

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air conditioning has a target temperature control system that can be changed according to the ambient temperature and realizes highly efficient operation by adjusting the optimum water temperature depending on the load.

The indoor unit has an integrated hot water storage tank and can be operated while automatically switching the water flow in response to the air conditioning requirements and the occurrence of water heating load. The hot water tank is equipped with an auxiliary heater (9kW) so that the heater can be used not only for hot water supply, but also as a heat source in the case of a temporary capacity shortage due to an abrupt increase in heating load (**Figure 2**).

Instead of an auxiliary heater, other exterior heat sources such as solar water heaters or boilers can be combined, allowing the flexible construction of an individual heating system depending on customer use including required heat load and heat source, etc., all of which contribute to the reduction of energy costs.

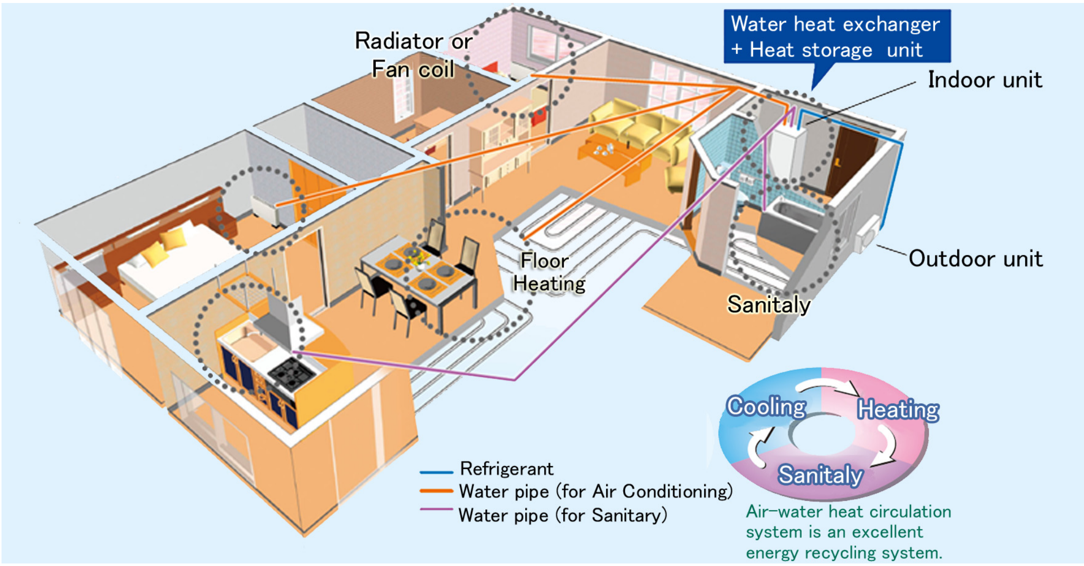

Figure 1 Overview of system
The system can use fan coils, radiators and floor heating. It can also handle sudden increases in hot water load through the use of a built-in storage tank.

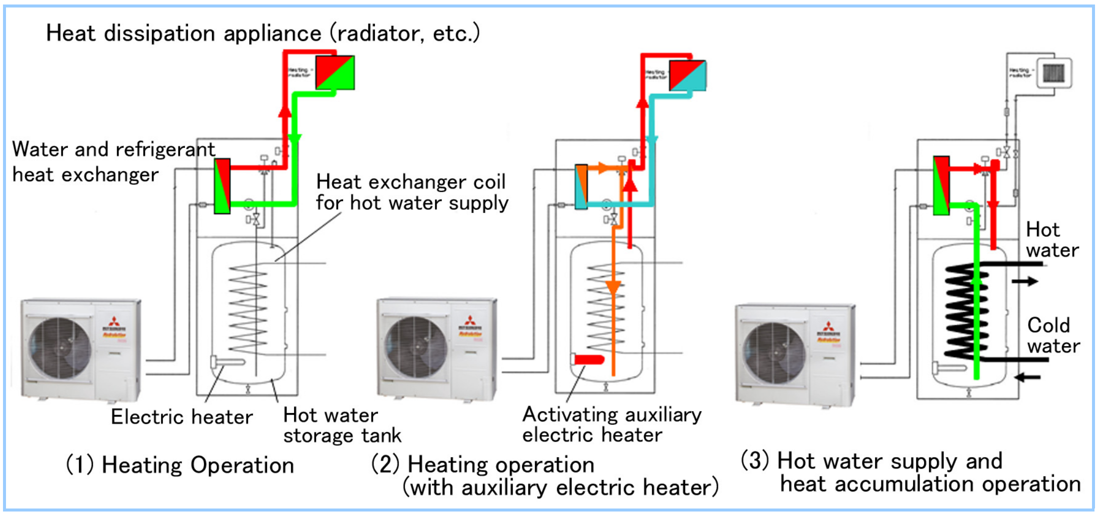

Figure 2 Examples of water flow control by operation mode
There are three water flow control mode options:
(1) Heating load is covered only by the capacity of the heat pump, (2) Capacity shortage because of heating overload, and (3) Water flow switching because of occurrence of water heating load.
When additional increases in both heating load and hot water supply load occur simultaneously, the system switches between modes (1) and (3) as appropriate.

3. Overcoming Technological Difficulties

Because air-to-water heat pumps for water heating systems differ from conventional air conditioners in terms of operating conditions and environment, a review of the main components and control system can realize a hot water discharge temperature of 58°C even at an ambient temperature of -20°C. The adoption of the same platform for the air conditioning heat source as is used in conventional systems – which have an abundant record of use – facilitates the common use of components and improves the marketability and reliability of the product (**Figure 3**). The items modified from conventional air conditioners are described below.

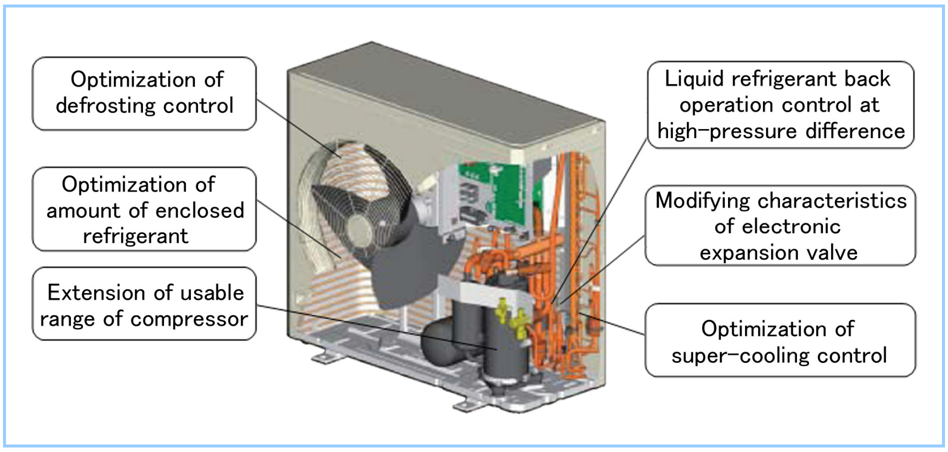

Figure 3 Improvements to outdoor unit

(1) High compression-ratio operation control by liquid refrigerant back operation control

Since the ambient temperature can fall to about -20°C in northern and inland areas of Europe, it is necessary for heating equipment to be able to maintain stable operation with water discharged at a high temperature even at low ambient temperatures.

In a conventional air conditioner, the temperature of the air discharged inside of a room needs to be more than 40°C to avoid cold drafts, so that in this condition there needs to be about 2.5MPa in high pressure for the compressor (the pressure at condensation saturation temperature). In an air-to-water heat pump for hot water heating use, on the other hand, a higher water temperature is needed depending on the type of radiator, such that during hot water supply operation, a water discharge temperature of up to about 60°C is required. At that time the maximum required high pressure is about 3.8MPa, which is higher than that of a conventional system.

To increase the high pressure under a low ambient temperature, it is necessary for the compressor to be operated under a high compression ratio. A gas refrigerant, on the contrary, has the property that when adiabatically compressed at a high compression ratio, the temperature of the refrigerant gas rises. Accordingly, the operation of a compressor with a high compression ratio will likely cause refrigerant oil to degrade and the motor magnet to demagnetize, etc., which can substantially affect the reliability of the system (**Figure 4**).

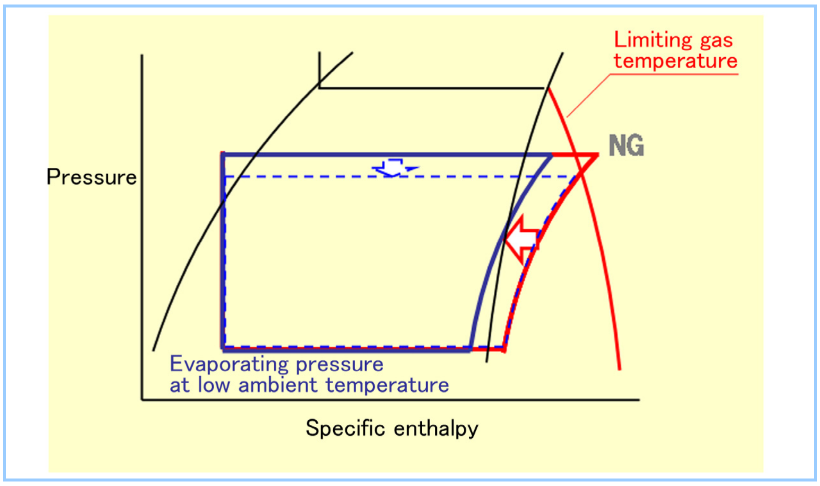

Figure 4 Refrigerating cycle chart at low ambient temperature
The red line shows that the gas discharge temperature crosses a threshold in the case of high-pressure-difference operations, the blue dashed line shows how to avoid the gas discharge temperature using the conventional control and the solid line shows the new control.

In a conventional air conditioner system, to prevent the discharge temperature of the refrigerant from the compressor from exceeding the limiting temperature in the case of an ambient temperature drop, operations are conducted while restraining the high pressure and compression ratio by reducing the rotational frequency of the compressor; thus, the temperature and the amount of water supplied can decline when operating at a low ambient temperature if the protective control adopted for the conventional air conditioner is applied to the air to water heat pump. Therefore, in this product, modified controls in which the temperature of the discharged refrigerant gas is controlled to be less than the limiting temperature by returning the liquid refrigerant to a compressor to cool therein are adopted, aiming to prevent a reduction in the capacity of the compressor and maintain stable operations for hot water supply in cold regions.

In order to achieve the above controls, a certain level of compressor durability is required to facilitate high-compression-ratio operation while sucking the liquid refrigerant, which is not experienced in a conventional air conditioner (**Figure 5**).

To determine the suitability of the compressors used in conventional air conditioners, studies were carried out to determine whether the loads applied to the sleeve of the bearing and the blade portions are within the design criteria under operating conditions, i.e., a hot water discharge temperature of 58°C and an ambient temperature of -20°C, which is the lowest service condition. As a result, it was ascertained that since the compressor can be used under high-compression-ratio operations on the basis of the specifications, a durability test was conducted as additional verification and the progress of the wear of the blade and bearing portion was observed.

In comparison with the durability tests of conventional air conditioners, major differences in the amounts of wear between the two sets of test data were not seen (**Figure 6**), nor was the progress of wear from the start of operations observed. This showed that a conventional compressor can have equivalent durability even under high-compression-ratio operations and can be applied to a heat pump for hot water heating. As a result, stable high-temperature water discharge operation in cold regions was validated.

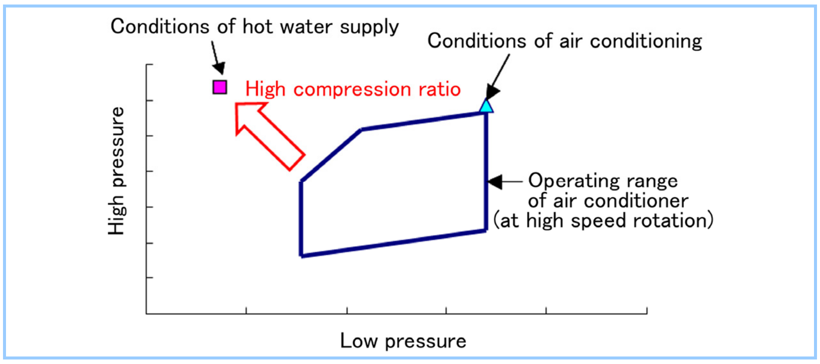

Figure 5 Operating range of compressor in conventional air conditioner and predicted service conditions in new product

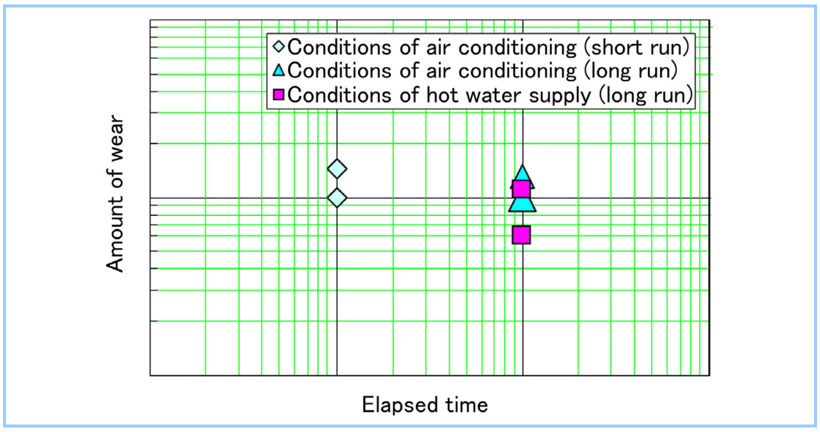

Figure 6 Correlation between compressor durability elapsed time and amount of wear

(2) Optimization of defrosting operations

In the indoor heat exchanger of an air to water heat pump, water and refrigerant are heat exchanged, making it important for defrosting operations during heating or cooling operations that due consideration be given to the freezing and breakage that arise from the drop in water temperature. Particularly in defrosting operations at a low ambient temperature, the low pressure of an indoor heat exchanger (the pressure at evaporation saturation temperature) declines, increasing the risk of freezing.

In this product, to avoid the freezing of circulation water, the compressor speed and the opening of the expansion valve are controlled so that the water temperature and low pressure will reach the appropriate level. When there is a risk of a decline in the water temperature and low pressure because of a shortfall in the heat source due to a defrosting operation, the water flow is switched to ensure the heat source so as to employ the heat accumulated in the hot water tank, preventing the freezing of the water heat exchanger.

(3) Modifying characteristics of expansion valve

In operations at a low ambient temperature, the evaporation temperature of the refrigerant in the evaporator declines, decreasing the amount of circulated refrigerant. To achieve high-compression-ratio operation with a small circulation amount, it is necessary to narrow the opening of the expansion valve and fine control of the range of the narrow valve opening is necessary. In a conventional expansion valve, however, the resolution of the valve in the range of the narrow opening is large, resulting in concerns about significant fluctuations in operating conditions with each pulse action.

As a result of modifying the characteristics of the expansion valve and enhancing the control resolution in the range of the narrow valve opening, stable operation is realized even in high-compression-ratio operations, where the amount of circulated refrigerant is small.

(4) Reduction of amount of refrigerant

R410A is used as the refrigerant in the product. It is widely adopted in residential air conditioners in Europe and is the same refrigerant used in conventional air conditioners.

R410A is a refrigerant that is subject to control by European refrigerant regulations enacted in 2006, however, so it is desirable to reduce the load by as much as possible in consideration of environmental factors. Moreover, in the case of systems enclosing more than 3kg of refrigerant, checks for refrigerant leaks must be carried out once every year, which contributes to increased user expense and running costs.

In view of the above situations, by re-designing the length of the pipes to eliminate the need for additional charging on site, the initial amount of enclosed refrigerant was reduced to less than 3kg for two models, reducing user expense.

4. Comparison of Running Cost Advantages

High efficiency has been attained by using the same platform as MHI’s conventional air conditioner for the outdoor unit and optimizing the control for the expansion valve. This allows the FDCW100VNX system to secure one of the industry’s best COPs (Coefficient of Performance; expressed by Output Capacity divided by Electric Power Consumption), in which at the rated capacity (9kW), the COP is 3.60 for hot water discharged at 45°C and 4.44 for hot water discharged at 35°C.

However, in order to make a contribution to reducing user energy costs, not only is the COP at the rated conditions important, but so is efficiency throughout the year. Thus, a trial calculation of the running cost advantage in the case of replacing an existing gas boiler with MHI’s heat pump (HMA100V+FDCW100VNX) was conducted, validating the cost reduction effect. Under standard European climate conditions[1] (Strasbourg; **Figure 7**) and assumed annual loads of 28,000kWh, the running cost of an existing boiler under continuous use is about 1,940 euro versus that of a heat pump of about 1,100 euro, resulting in an expected reduction in the running cost of about 840 euro per year (**Table 1**)[2].

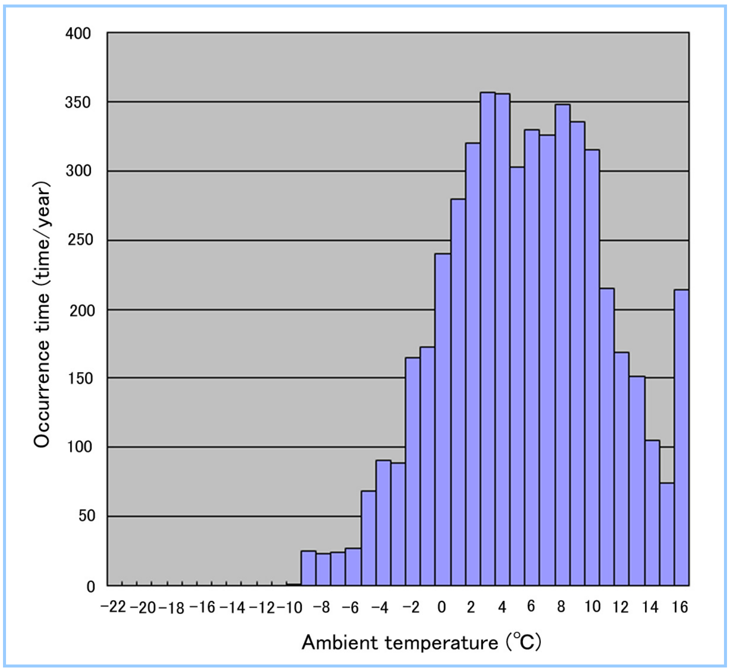

Figure 7 Occurrence time of ambient temperature in average European climate (Strasbourg)

Table 1 Comparison of running cost

	Amount of energy used (kWh/year)	Energy unit cost (euro/kWh)	Running cost (euro/year)	Cost advantage (euro/year)
Heat pump + auxiliary heater	10,024 (9,142+882)	0.1099	1,102	842
Gas boiler	40,000	0.0486	1,944	-

Calculation conditions

- Required annual capacity: 28,000 kWh (including hot water supply: 200 L/day)
- Gas boiler efficiency: 70%
- Ambient temperature conditions: standard European climate conditions (Strasbourg; Figure 7)
- Water discharge temperature: 45°C (EN14511 standard water discharge conditions)
- Energy unit cost: Standard price in France used[2]

In this trial calculation, loads at temperatures below -1°C surpass the capacity of the heat pump (**Figure 8**), so a built-in heater starts to work to compensate for the shortfall in the heat source. The use of the electric heater may be a factor in the worsening of efficiency, but the proportion of the auxiliary heat source to the required overall capacity is only about 3% annually (**Figure 9**), which is not a significant drag on annual efficiency. In addition to an electric heater as an auxiliary heat source, an existing boiler may be used to further reduce the running cost, allowing flexible designs according to customer requirements.

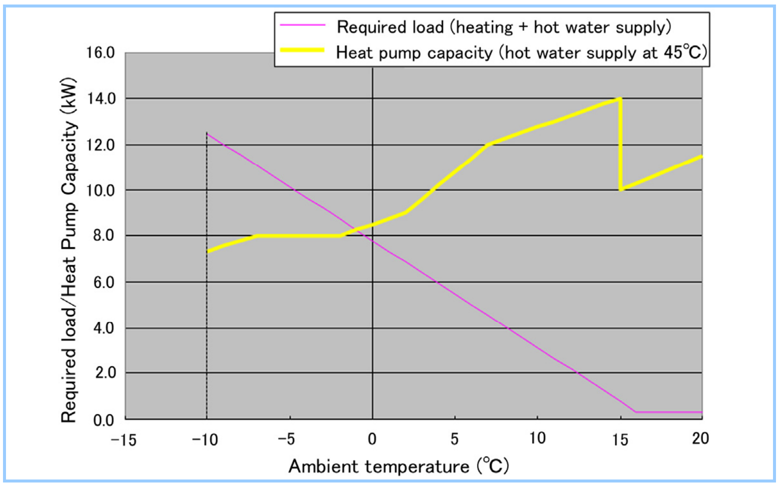

Figure 8 Heat pump capacity and required load assuming hot water discharge operation of 45°C
Required loads are assumed under standard European climate conditions and annual required loads of 28,000 kWh.

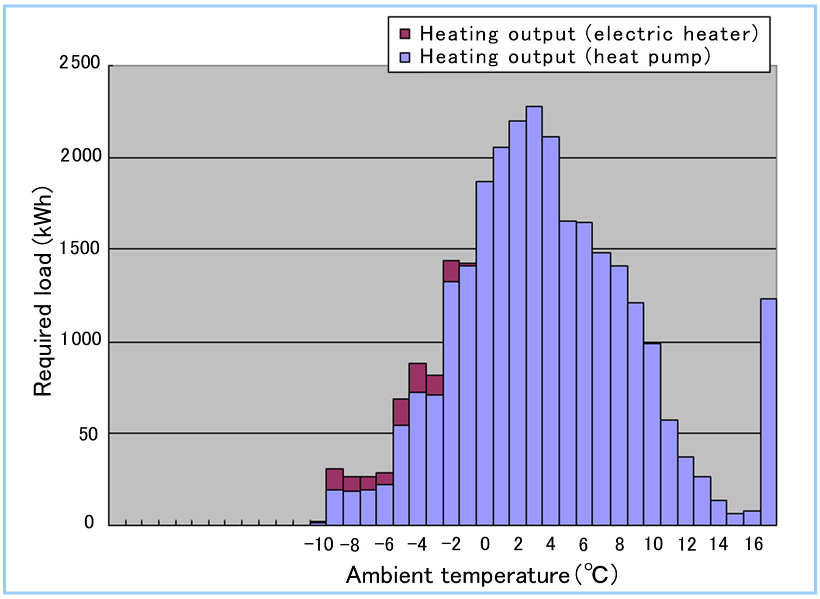

Figure 9 Annual heating output by heat source
Required load value for ambient temperatures over 16°C designates the total value of hot water supply load at ambient temperatures over 17°C.

5. Field Tests

To validate product reliability, field tests were carried out at eight locations in Europe in collaboration with NIBE (**Figure 10**). As a representative example, the case of Östersund in the middle of Sweden (item (1) in Figure 10) is introduced here. The field test was conducted at a selected normal house with a total floor area of 200m^2 and using radiators as heat dissipation appliances (**Figure 11**).

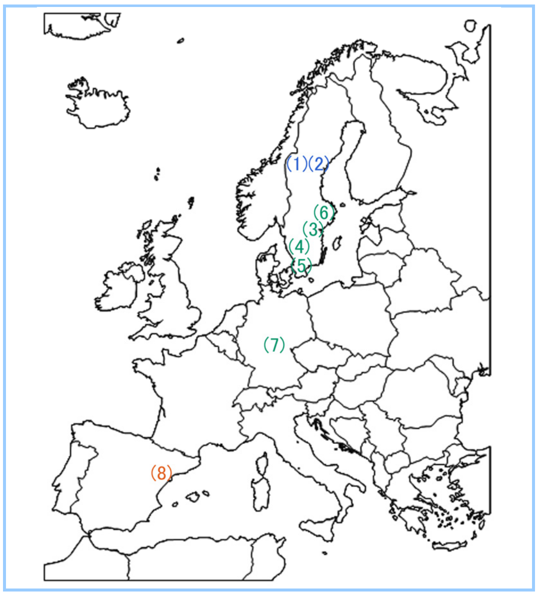

Figure 10 Field test locations
Cold regions: 2 locations, Normal regions: 5 locations, Warm regions: 1 location

Figure 11 Field test site at Östersund (cold region)
Floor Area: about 200m^2, Number of Residents: 2, Heating System: Radiators, Assumed Annual Heating Load: about 32,000kWh

The actual data with respect to the temperature transition of the water supplied by heat pump operation are shown in **Figure 12**. In the figure, temporary drops in water temperature indicate defrosting operations.

The hot water discharge temperature is controlled at around 40°C in relatively high ambient temperature zones in the daytime, but as can be seen, targeted hot water discharge temperatures increase as the ambient temperature decreases. In this manner, optimizing the targeted temperature in response to the change in load allows effective operation to be realized.

Field tests have continued since 2008 and have validated the air-to-water heat pump is utilized as a stable and useful heat source in user homes even in cold regions of Europe.

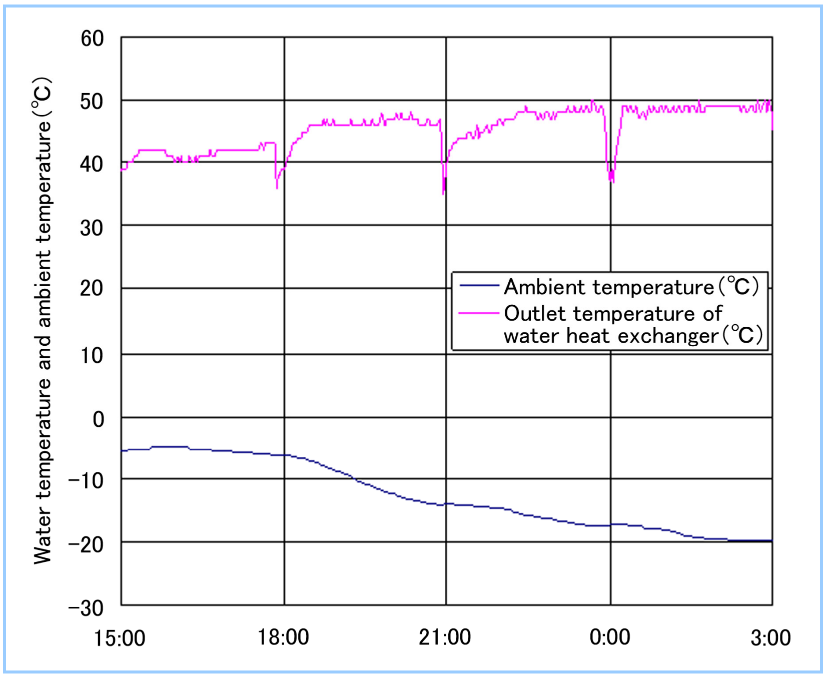

Figure 12 Transition of ambient temperature and water temperature
The targeted water temperature is automatically regulated depending on the ambient temperature, so that the outlet temperature rises during the night when the ambient temperature drops.

6. Conclusion

With the collaboration of NIBE, one of the leading manufacturers of heat pumps in Europe, MHI has developed a lineup of three models of heat pump systems of 8, 9 and 16kW and entered the home heat pump market in Europe, which is expected to expand for the foreseeable future.

While the outdoor unit seeks to share the components of a conventional air conditioner, the components and control system necessary under new service conditions are being reviewed and modified to enhance product marketability.

We will continue to develop and provide new heat pump systems with high efficiency and high temperature water discharge that can be accepted by the heating cultures of cold regions according to market needs.

References

1. ECEEE, http://www.eceee.org/Eco_design/products/boilers/
2. Europe's Energy Portal, http://www.energy.eu/