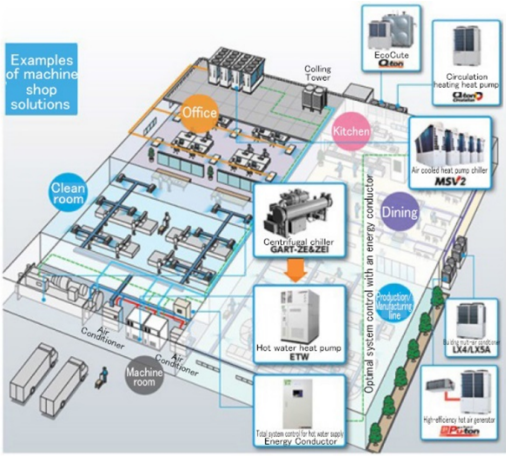
Heat Pump Technology to Reduce CO_2 Emissions and Running Costs by Replacing Boilers



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Mitsubishi Heavy Industries, Ltd. (MHI) Group puts priority on contributing to the achievement of carbon neutrality through its business activities. Shifting the heat source from fossil fuel combustion to electrified heat pumps is an effective way to achieve this. With this heat pump technology, MHI Group will market heat pump products with reduced running costs so that a wide range of customers will use our heat pumps. As such, we intend to reduce CO_2 emissions in society as a whole and will continue to contribute to the realization of a carbon-neutral society through the development of technologies.

1. Introduction

MHI Group has declared the realization of a carbon-neutral society through our business activities as a key management issue, aiming to achieve Net Zero by 2040. One of the ways to achieve this is to aggressively expand the use of heat pumps, not only to reduce CO_2 emissions through direct combustion as in the past, but also to actively utilize renewable energy sources by promoting electrification. Most of the heat sources used for the industrial field, such as boilers, are fossil fuel-combustion. In order to expand the use of heat pumps in this market, it is effective to improve the economic efficiency and convenience entirely from the heat source to the user side. This report introduces the heat pump technology by presenting MHI Group's efforts to apply heat pumps to various applications as a replacement for boiler heat sources.

2. Shifting from boiler to heat pump

Currently, most of the high-temperature heat sources used in the industrial field are provided by boilers, and their total heat demand is estimated to be approximately 13,000 TWh in 2020. **Figure 1** shows the percentage of total heat demand by temperature range. The actual demand temperature below 200°C accounts for 48% of the total demand, and in particular, below 100°C accounts for one third of the total demand. The CO_2 emissions from the heat sources for the demand temperature range below 100°C are approximately one megaton CO_2, assuming a boiler system efficiency of 80% and gas combustion of 200 g/kWh.

Heat pumps have a characteristic that the smaller the temperature difference between the heat source side and the use side, the greater their coefficient of performance (COP), and the more efficient they can be in transporting heat. Therefore, MHI Group has been marketing products that utilize heat pumps mainly for the demand temperature range of 100°C or lower among the mainstream demand temperature range of 200°C or lower to promote the replacement of boilers, thereby contributing to reductions in energy in a crude oil equivalent and CO_2 emissions. If all boiler heat sources for the demand temperature range of 100°C or lower are replaced with heat

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pumps powered by renewable energy, it would be possible to reduce approximately one third of the CO_2 emissions resulting from the use of heat source device in the industrial field.

Figure 2 shows heat pump products that MHI Group brings to the market by the capacity and temperature range. In the next chapter, we will introduce four cases of heat pump technology using air heat sources, which are easy to be designed and installed, as examples of the heat pump technologies being worked on by the temperature range.

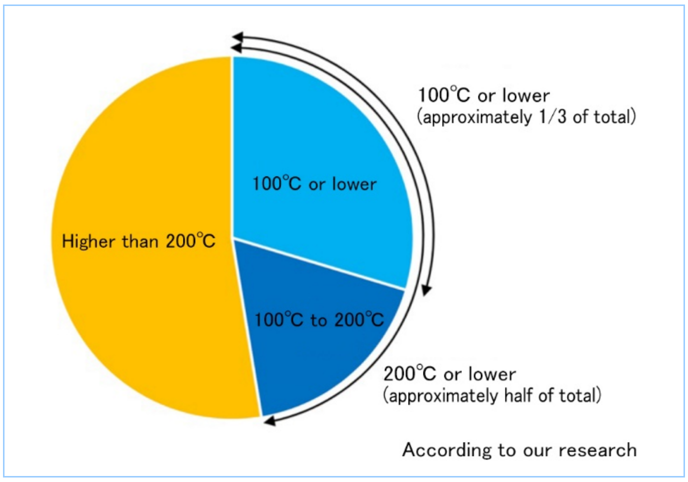

Figure 1 Total global heat demand (13,000 TWh) by temperature range

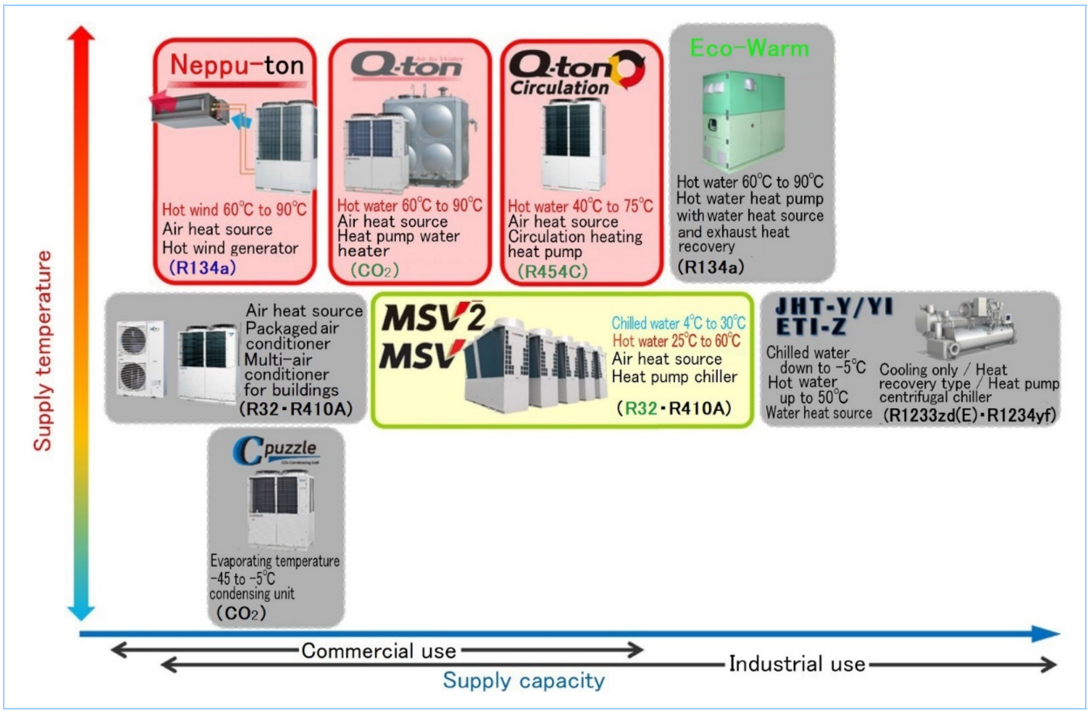

Figure 2 Our heat pump product line

3. Technologies for products MHI Group is working on by supply temperature range

3.1 Hot wind generator "Neppu-ton"[1]

(1) Product technology overview

This product is a heat pump that generates 90°C hot wind using an air heat source, and was developed to replace boilers and electric heaters used as a heat source for drying device. Obtaining high-temperature hot wind or hot water by general heat pumps requires a system that recovers heat from factory waste hot water to reduce the temperature difference between the heat source device and the hot wind generator. Such a system requires water piping to circulate waste hot water, and therefore there arise issues that the system is complicated, the cost is high, and ensuring the installation space is difficult. To solve these issues, this product was designed to consist of two components like ordinary air conditioners: a heat source unit (an outdoor unit) that draws heat from the atmosphere and a hot-wind generator (an indoor unit) that can directly generate hot wind. This product design made it possible to install the hot wind generator near factory device where hot wind is used. Since the waste hot water piping is no longer necessary, it is easy to install additional device to increase the capacity of the factory, which allows the heat pump system to be used more widely in the industrial field. Furthermore, this product adopts a highly efficient system with a two-stage compression cycle, which makes it possible to blow hot wind at 90°C even though air is used as the heat source.

(2) CO_2 emissions reducing effect

In the example case of applying this product to hot wind supply system for a dry laminator, this product was introduced as a replacement for a conventionally used heating device that generated hot wind of 70°C to 80°C using a steam coil. **Figure 3** shows a system diagram of the hot wind supply device to which our product was introduced. New ducts were installed upstream of the existing steam coil, and the hot wind generator was installed to supply hot wind of 70°C to 80°C as intake air preheating. Even when the output of the heat pump heat source unit drops due to defrosting operation, the temperature supplied to the dry laminator is maintained at a constant level by bypassing the heat pump heat source through the existing ducts and using the steam coil for heating. Similarly, in the event of a heat pump failure, the existing ducts are used to secure an airflow path, allowing the dry laminator to continue operation.

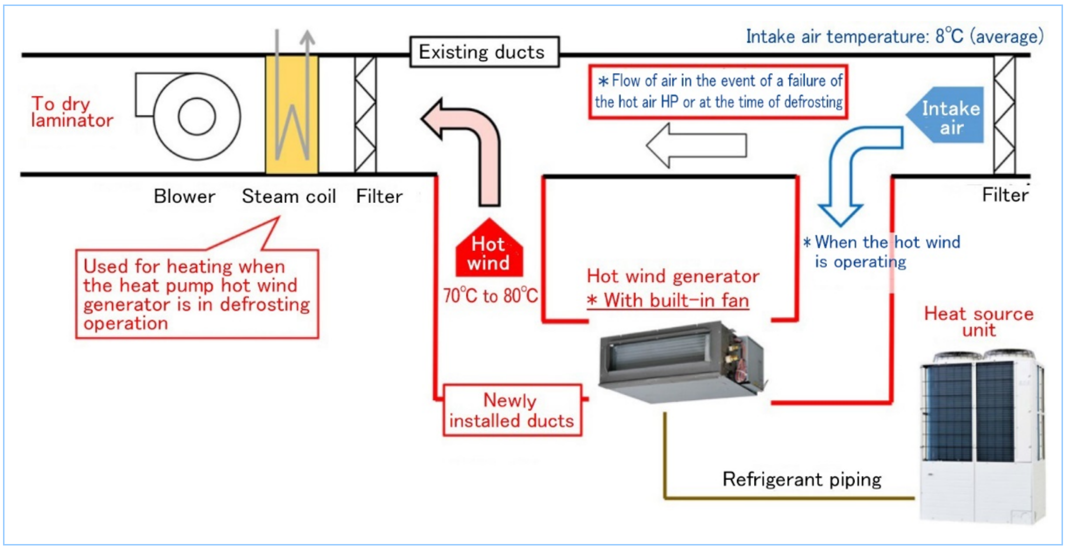

Figure 3 Hot wind supply system for dry laminator

Figure 4 shows an example of estimating the effect of introducing this system, and **Table 1** shows the estimation conditions. In addition to the unit energy cost and CO_2 emissions, Table 1 also shows the value obtained by converting the electricity used by this system to primary energy. As a result of the demonstration test conducted for approximately one month from late November to late December, energy consumption, CO_2 emissions, and running costs were all reduced by approximately 50% compared to the conventional steam heater. These positive results are because this system is located close to the place of use in addition to the efficiency improvement due to the heat pump, whereas the boiler is not installed close to the place of use and its efficiency drops to about 0.6 when heat loss in the piping is included. This demonstration test confirmed the achievement of both environmental load reduction and high economic benefits in winter, and we expect this system to be even more effective on an annual basis.

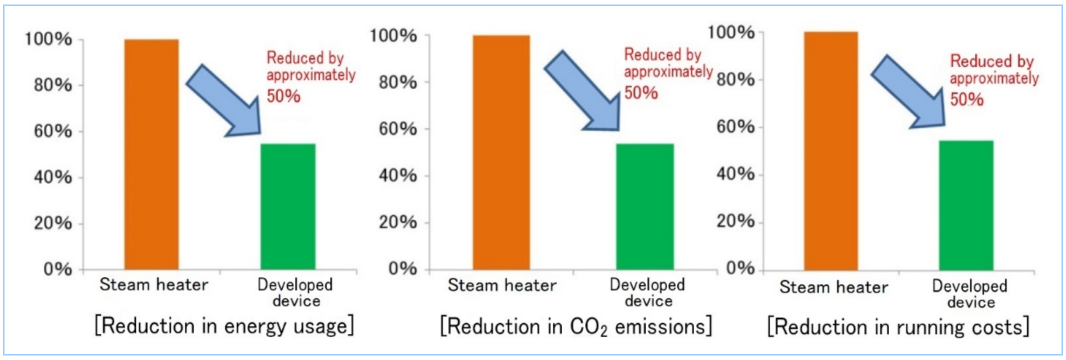

Figure 4 Example of estimating effect of introducing developed system

Table 1 Conditions for estimating effect of introducing developed system

Item		Unit	Value
Unit calorific value of city gas		MJ/Nm^3	45.0
Primary energy equivalent of electricity		MJ/kWh	9.76
CO_2 emissions	Electricity	kgCO_2/kWh	0.496
	City gas	kgCO_2/Nm^3	2.29

Source:
- Unit calorific value of city gas: Value set in Act on Promotion of Global Warming Countermeasures
- Primary energy equivalent of electricity: Value set in Act on the Rational Use of Energy
- CO_2 emissions (Electricity): Tokyo Electric Power Company Holding, Inc.'s emissions factor for submission in 2017 (adjusted emissions factor), https://www.env.go.jp/press/106320.html
- CO_2 emissions (City gas): Values published by Tokyo Gas Co., Ltd. (Tokyo Gas website), https://www.tokyo-gas.co.jp/network/gas/shurui/index.htm

3.2 Commercial-use water heater "Q-ton"(2)

(1) Product technology overview

This product was developed to replace boilers that use fossil fuels and electric heater-type water heaters. Conventional air source heat pumps have a problem in that their heating capacity decreases when the outside air temperature is low, and they have not been widely used in cold regions. To solve this problem, this product employs a two-stage compression gas injection cycle that increases the amount of gas cooler refrigerant circulating at low outdoor temperatures by using a two-stage compression process for CO_2 refrigerant, which is a natural refrigerant, and injecting gas refrigerant at the intermediate pressure. As a result, the same capacity as the rated capacity is maintained at the inlet water temperature of 17°C and the outside air temperature of -7°C, and more than 70% is maintained at the outside air temperature of -20°C. Furthermore, hot water of 90°C can be produced at a lower outside air temperature of -25°C. In addition, the use of CO_2 with a GWP (Global Warming Potential) of 1 as a refrigerant has also been highly evaluated, and the use of this product is spreading to hotels, hospitals, food service centers, and other facilities in cold regions.

(2) CO_2 emissions reducing effect

Figure 5 shows example cases in which this product was installed in existing hot water supply device using a boiler. The system installed in east Hokkaido mainly supplies hot water for machine washing, and the system installed in north Iwate Prefecture supplies hot water for sanitary use. Both of these demonstration tests were conducted in some of the coldest regions in Japan, and it was confirmed that our product could supply hot water without any problems even in winter.

Figure 6 shows examples of estimating the effect of introducing this system, and **Table 2** shows the estimation conditions. Compared to a boiler assuming a system efficiency of 80%, the primary energy consumption could be reduced by slightly less than 20%, the running cost by slightly more than 50%, and CO_2 emissions by slightly less than 30%, clearly demonstrating the superiority of this technology over boilers.

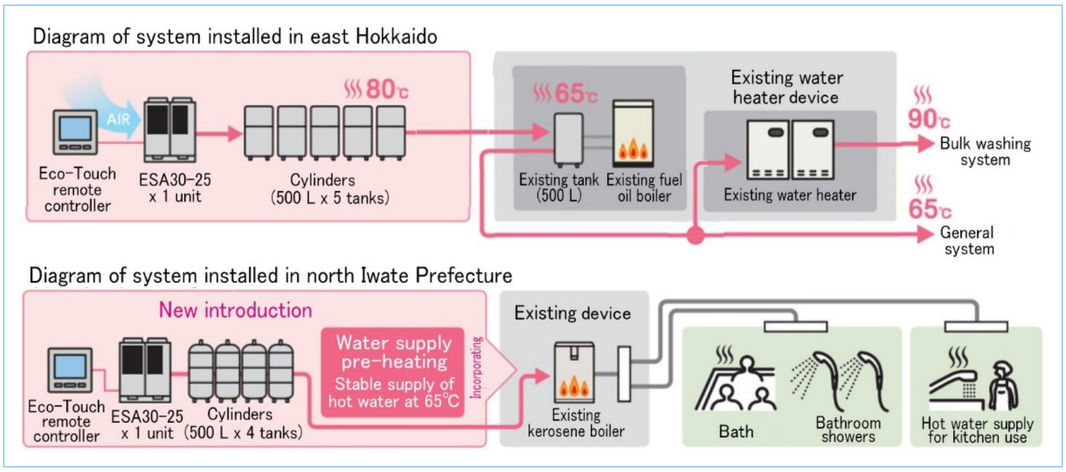

Figure 5 Diagram of introduced Q-ton systems

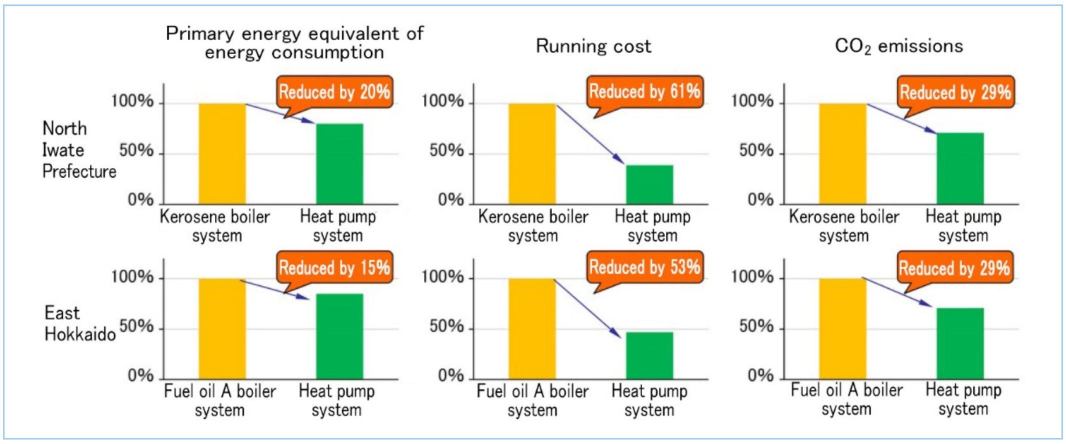

Figure 6 Examples of estimating effect of introduced Q-ton systems

Table 2 Conditions for estimating effect of introduced Q-ton systems

Location		Unit price	CO_2 emissions	Primary energy equivalent
North Iwate Prefecture	Electricity	Summer: 11.65 yen/kWh Other seasons: 10.70 yen/kWh	0.546 kg-CO_2/kWh	9.76 GJ/10^3 kWh
	Kerosene	90 yen/L	2.49 kg-CO_2/L	36.7 GJ/kL
East Hokkaido	Electricity	Night time: 6.5 yen/kWh Daytime: 13.0 yen/kWh	0.680 kg-CO_2/kWh	9.76 GJ/10^3 kWh
	Fuel oil A	84 yen/L	2.71 kg-CO_2/L	39.1 GJ/kL

* Other conditions: System efficiency of existing boiler is 80%

Source:
- CO_2 emissions (Electricity): Tokyo Electric Power Company Holding, Inc.'s emissions factor for submission in 2017 (adjusted emissions factor), https://www.env.go.jp/press/106320.html
  CO_2 emissions (Kerosene and fuel oil A): Ministry of the Environment's website, Greenhouse Gas Emissions Calculation, Reporting, and Publication System
  List of Calculation Methods and Emissions Factors for Calculation, Reporting, and Publication System,
  https://ghg-santeikohyo.env.go.jp/calc
- Primary energy equivalent (Electricity): Value set in Act on the Rational Use of Energy
  Primary energy equivalent (Kerosene, fuel oil A): Agency for Natural Resources and Energy's website, List of standard calorific values by energy source (2005)
  https://www.enecho.meti.go.jp/statistics/total_energy/carbon.html

3.3 Water chiller/heater MSV (Mitsubishi Smart Voxcel)(3)

(1) Product technology overview

This product is a versatile air-cooled heat pump chiller designed to meet the demand not only for air conditioning applications using fan coil units, but also for the replacement of factory boilers used for heating parts washing tanks in factory manufacturing processes. Many washing tanks need to be heated so as to maintain the temperature at 55°C to 60°C throughout the year. Conventional air-cooled heat pump chillers have issues that the heating temperature is limited by an excessive increase in the refrigerant pressure and operation under high outside air temperature conditions, which tend to cause an increase of the refrigerant pressure, is impossible due to the large absorption. This product enables heating operation up to 60°C and continuous operation at an outside air temperature of 43°C by optimizing control of the refrigerant flow rate to the condenser and controlling the blower of the evaporator, making it possible to meet the demand for replacement of industrial boilers.

(2) CO_2 emissions reducing effect

Figure 7 shows a system that assumes the introduction of this product into a washing process for machine parts. This system mainly uses a heat pump to heat the washing solution in the washer, from using only steam from a boiler. Since the washing solution is corrosive, the system provides heating thereto via an indirect heat exchanger in a newly installed hot water circulation piping circuit. We estimated the effect of the introduction of the system assuming a heating load of 150 kW, a temperature increases from 55°C to 60°C, and an operating time of 3,840 hours per year.

Figure 8 shows an example of estimating the effect of the introduction, and **Table 3** shows the estimation conditions. The annual electric energy consumption calculated by integrating the amount of electricity used during winter, summer, and the intermediate period resulted in an approximately 44% reduction in running costs and an approximately 40% reduction in CO_2 emissions compared to the boiler, indicating that this technology is expected to be superior to the boiler. An equivalent system is currently in operation at MHI Group.

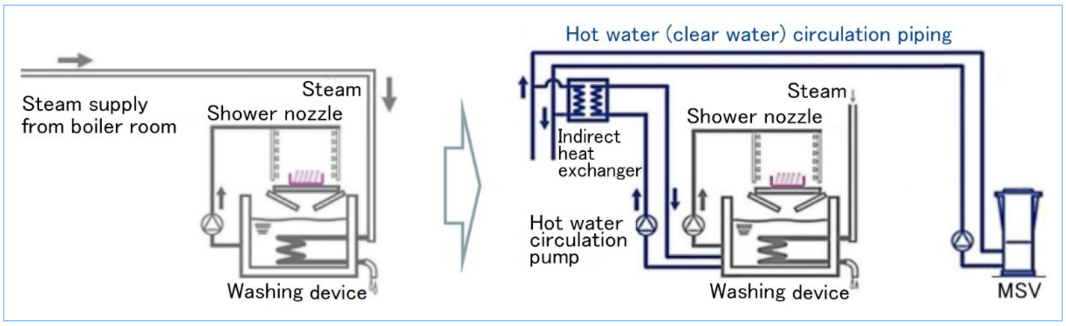

Figure 7 Example of introducing our product to part washing process

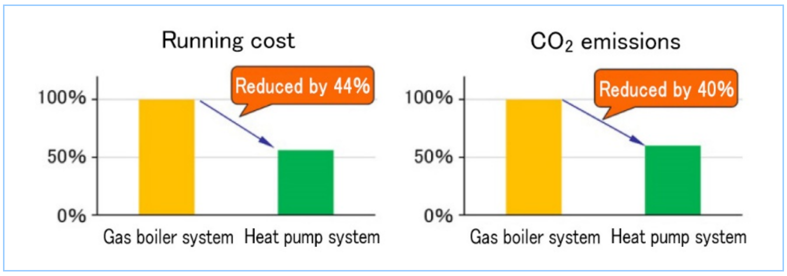

Figure 8 Example of estimating effect of introducing our product to part washing process

Table 3 Conditions for estimating effect of introducing our product to part washing process

Load condition	Heating load	150 kW
	Heating temperature condition	55°C -> 60°C
	Operating hours	Operating hours 3840 hours/year (16 hours/day x 240 days/year)

		Unit price	CO_2 emissions	Primary energy equivalent
Estimation conditions	Electricity	Electricity Basic charge: 1,800 yen/kWh Summer: 11.65 yen/kWh Other seasons: 10.70 yen/kWh	0.494 kg - CO_2/kWh	(Daytime) 9.97 MJ/kWh (Nighttime) 9.28 MJ/kWh
	Gas	94.09 yen/Nm^3	2.29 kg - CO_2/Nm^3	45.0 MJ/Nm^3 (HHV)

* Other conditions
COP of heat pump: (Winter: 5.6°CDB) 2.50, (Mid-season: 18.1°CDB) 2.90, (Summer: 26.3°C DB) 3.20
System efficiency of existing boiler: 70%

Source:
- CO_2 emissions (Electricity): Tokyo Electric Power Company Holding, Inc.'s emissions factor for submission in 2017 (adjusted emissions factor), https://www.env.go.jp/press/106320.html
  CO_2 emissions (City gas): Values published by Tokyo Gas Co., Ltd. (Tokyo Gas website), https://ghg-santeikohyo.env.go.jp/calc
- Primary energy equivalent (Electricity): Value set in Act on the Rational Use of Energy
  Primary energy equivalent (City gas): Value set in Act on Promotion of Global Warming Countermeasures
  https://www.enecho.meti.go.jp/statistics/total_energy/carbon.html

3.4 Circulation heating heat pump "Q-ton Circulation"(4)

(1) Product technology overview

In some cases, the temperature of hot water used in the degreasing process after cutting and the parts cleaning process in machine parts factories and for the cleaning of manufacturing device in food factories is around 70°C, which is higher than the supply temperature of the water chiller/heater mentioned above, and it is necessary to select a refrigerant suitable for such temperature and employ a high-efficiency cycle. This product is an air source circulation heating heat pump for these applications, and can provide 75°C hot water (inlet/outlet temperature difference 5°C) under ambient air temperatures from -20°C to 43°C. The use of this air source heat pump eliminates the need to prepare waste hot water and avoids complicated system design and installation during the introduction. In order to enable a circulation hot water supply function with high temperature and a small difference between the input and supply water temperatures, R454C, a low-GWP refrigerant, is used. On the other hand, since air source heat pumps have the characteristic that the heating capacity decreases as the outside air temperature decreases, a two-stage compression gas injection cycle is used to address this issue, similarly to Neppu-ton and Q-ton.

(2) CO_2 emissions reducing effect

Figure 9 shows an example of using this product for heating a washing tank in a food factory. The conventional system circulate-heats hot water from the existing open tank through a heating plate that uses heat from a fossil fuel-combustion steam boiler. For introducing this product, a circulation circuit for heating by the heat pump was newly added to the open tank to heat the water to 70°C.

Figure 10 shows an example of estimating the effect of introducing the product on reduction of annual running costs and CO_2 emissions based on the operation data from September 2018 to March 2019, and **Table 4** shows the estimation conditions. The electricity rates were calculated from the actual measured electricity consumed by the product. The running cost before the introduction of this product was calculated by back-calculating the fuel consumption of the existing boiler based on the heating capacity of this product to compare the energy-saving effects. As a result, a reduction of approximately 50% was achieved in energy consumption, CO_2 emissions, and running costs.

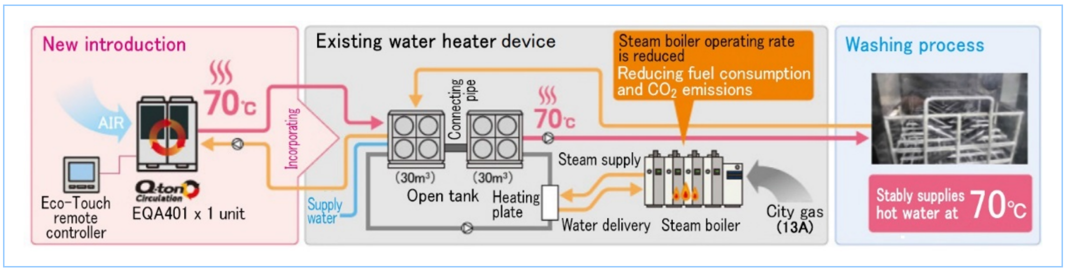

Figure 9 Example of introducing our product for heating washing tank in food factory

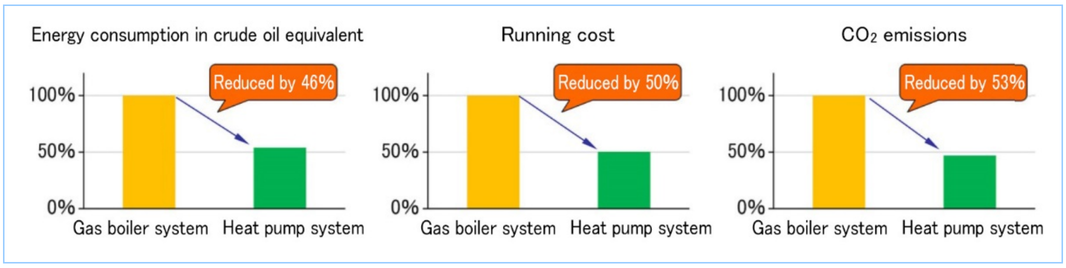

Figure 10 Example of estimating effect of introducing our product for heating washing tank in food factory

Table 4 Conditions for estimating effect of introducing our product for heating washing tank in food factory

Item		Unit	Value
Lower calorific value of city gas		MJ/Nm^3	40.6
Primary energy equivalent of electricity		MJ/kWh	9.76
CO_2 emissions	Electricity	$kgCO_2/kWh$	0.496
	City gas	$kgCO_2/Nm^3$	2.29

Source:
- Lower calorific value of city gas: Values published by Tokyo Gas Co., Ltd. (Tokyo Gas website) for gas having a unit calorific value of 45 MJ/Nm^3
  https://www.tokyo-gas.co.jp/Press/20041018-1.html
  Estimated lower calorific value from Iwatani Corporation's fuel comparison chart (Iwatani website)
  https://www.iwatani.co.jp/jpn/business/energy/basic-knowledge/fuel/
- Primary energy equivalent of electricity: Value set in Act on the Rational Use of Energy
- CO_2 emissions (Electricity): Tokyo Electric Power Company Holding, Inc.'s emissions factor for submission in 2017 (adjusted emissions factor)
  https://www.env.go.jp/press/106320.html
- CO_2 emissions (City gas): Values published by Tokyo Gas (Tokyo Gas website)
  https://www.tokyo-gas.co.jp/network/gas/shurui/index.html

4. Conclusion

This report presented examples of heat pumps that have already been commercialized as one of MHI Group's top priority technologies for achieving carbon neutrality worldwide.

This report mainly focused on the products of MHI Thermal Systems, Ltd. and introduces our efforts in the supply temperature range of 100°C or lower and output of less than 100 kW; MHI Group, however, is also working on heat pump technologies in the supply temperature range of 100°C or higher and large output. For example, Turboden S.p.A. (Italy), an MHI Group company, is working on high-temperature, large-scale applications of 3 to 30 MW per unit up to 200°C for district heating and industrial process applications.

With energy prices continuing to soar, it is expected that combustion will be further replaced by heat pumps because heat pumps are also effective in reducing running costs. MHI Group will extend the range of temperatures and capacities of our heat pump products in order to solve their issues and expand the range of applications to contribute to achieve carbon-neutrality.

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