14th IEA Heat Pump Conference
15-18 May 2023, Chicago, Illinois

Industrial Heat Pumps in Japan: Current Status and Future Prospects

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Abstract

The importance of industrial heat pumps for decarbonization has gained widespread recognition. Japan has demonstrated preeminence in the realm of industrial heat pump innovation and implementation. This paper overviews the current technology and market status of industrial heat pumps in Japan, demonstrating the maturity of heat-pumping technology to some extent. However, it shows a need to accelerate the introduction. Through a comprehensive questionnaire survey and barrier analysis, this study clarifies the challenges faced in the widespread adoption of industrial heat pumps and proposes measures to address these barriers in the future.

Selection and/or peer review under the responsibility of the organizers of the 14th IEA Heat Pump Conference 2023.

Keywords: Industrial heat pump; Technology status, Market status, Barrier analysis, Questionnaire survey

1. Introduction

Industrial heat pumps are recognized as a technology for decarbonizing industries due to their high efficiency and ability to be electrified with low-carbon electricity. According to the net-zero scenario of the International Energy Agency (IEA) by 2050 [1], industrial heat pumps will play an important role for low- (<100°C) and some medium- (100°C–400°C) temperature heat demand in light industries, accounting for approximately 30% of the total heat demand by 2050. To achieve this scenario, it is estimated that approximately 500 MW of industrial heat pumps must be installed each month over the next 30 years.

In Japan, the "Clean Energy Strategy," published in May 2022, prioritizes industrial heat pumps as a key decarbonization technology for heat demands below 200°C [2]. This strategy maps out the shift from our current energy system to one with a targeted 46% reduction in emissions by 2030 and an ultimate aim of reaching net-zero emissions by 2050. Industrial heat pumps are considered a practical solution due to their high efficiency and high technology readiness level compared to other alternatives.

The industrial heat pump technologies in Japan are regarded as unparalleled globally, and previous studies have reported on their technologies and application examples [3-5]. However, prior research has focused on specific and individual technologies. Conversely, this study takes a broader perspective, providing a comprehensive overview of the current status of industrial heat pumps in Japan. Moreover, it clarifies the barriers to its widespread adoption through a questionnaire survey and barrier analysis and proposes measures for future development.

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2. Current Status

This chapter provides an overview of the technology and market status of industrial heat pumps in Japan.

2.1. Technology status

Various types of industrial heat pumps have been commercialized in Japan, including closed and open systems such as mechanical vapor recompression (MVR). The closed-system is further divided into two categories: the air-source type (Fig. 1) and the water-source type (Fig. 2).

The air-source heat pump typically utilizes ambient air as the heat source. Given the latitudinal expanse of Japan, from north to south, the ambient temperature varies across regions and seasons, with an average temperature of approximately 15°C. In the light of the cost-competitive coefficient of performance (COP), the maximum heat supply temperature is limited to approximately 90°C. Some products have a maximum heating capacity of 150 kW–200 kW, whereas many others have a heating capacity of less than 50 kW. It is assumed to be distributed throughout each heating process. This distribution arrangement presents two potential benefits. Firstly, it has the potential to reduce the heat dissipation loss from the long steam pipes of a steam boiler system. Typically, steam boilers have a thermal efficiency of ~ 90%. However, considering the heat dissipation loss from steam pipes, the end-use efficiency was only ~ 50% [6]. Secondly, this distribution arrangement also offers the possibility of utilizing heat dissipation from industrial processes. Many heating processes raise the internal temperature of a factory by dissipating heat, leading to decreased worker comfort or increased air conditioning demand. By placing an air-source heat pump near the heating process within the factory, it is possible to reduce air conditioning demand and improve the heat pump COP by increasing its heat source temperature.

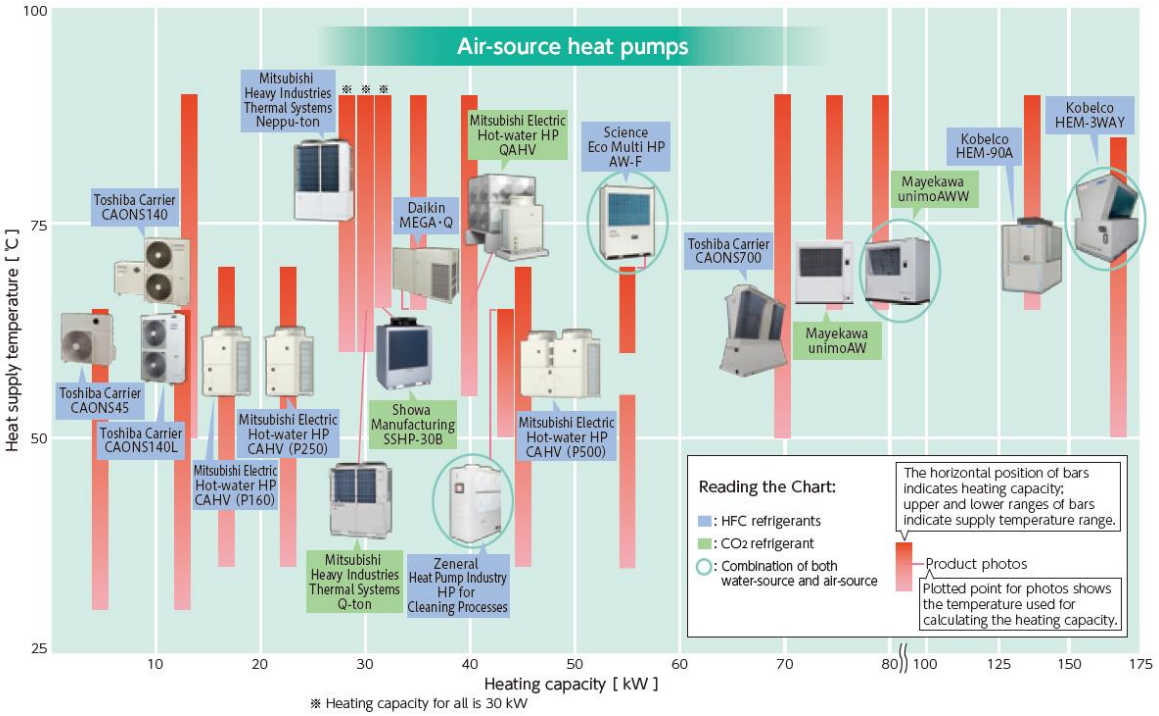

Fig. 1. Air-source industrial heat pumps available in the Japanese market [6].

Compared to the aforementioned air-source type heat pumps, water-source type heat pumps exhibit a wider range of heat supply temperature and heating capacity. They have a maximum supply temperature of 175°C, with a maximum heating capacity of ~ 600 kW. This type is primarily employed for waste heat recovery or simultaneous heating and cooling applications. To achieve economic viability for heat supply temperatures exceeding 100°C, relatively high-temperature waste heat is typically utilized as the heat source. At present in Japan, a COP of four is considered optimal for heat pump applications where heating is the sole objective. For combined heating and cooling applications, a total COP of five (with a heating COP of three) is recommended. The integration of a thermal storage tank is often required for simultaneous heating and cooling operations, as

heating and cooling demands may not occur concurrently. However, the addition of this tank can present barriers to the implementation of heat pumps, particularly in terms of capital cost and spatial constraint. Products circled in Fig. 1 are equipped with two evaporators and can switch between water and air heat sources. During periods where both heating and cooling are required, the water heat source is utilized. During periods where cooling is not necessary, the air heat source is employed.

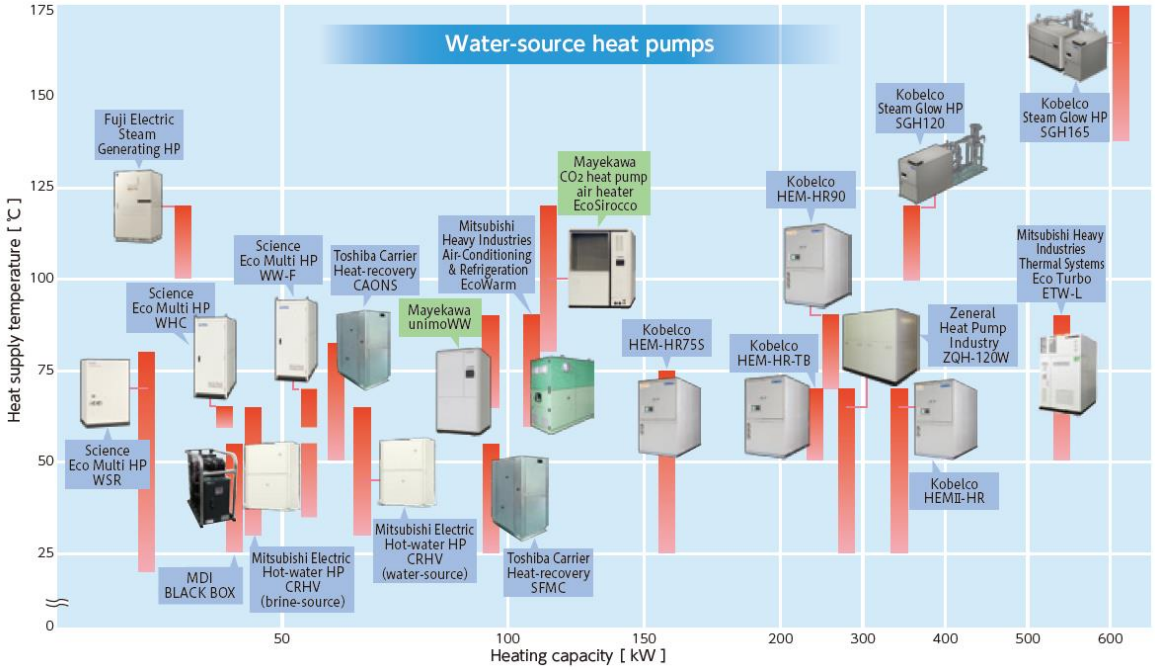

Fig. 2. Water-source industrial heat pumps available in the Japanese market [6].

While most of the heat pumps shown in Figures 1 and 2 have been commercially available for over a decade, they are still reliant on hydrofluorocarbon (HFC) refrigerants. Future technical challenges include lowering the global warming potential (GWP) of refrigerants and expanding the product lineup for high-temperature ranges. In national R&D projects led by New Energy and Industrial Technology Development Organization (NEDO), some manufacturers such as Fuji Electric, Mayekawa, and Mitsubishi Heavy Industries Thermal Systems are actively working on developing heat pumps with the capacity to supply heat at temperatures of 150°C or greater. Table 1 provides a comprehensive overview of this technology. The expansion of the product lineup for high-temperature range is expected in the near future.

Table 1. Under development high-temperature heat pumps in Japan

Manufacturer	Fuji Electric	Mayekawa	Mayekawa	Mitsubishi Heavy Industries Thermal Systems	Mitsubishi Heavy Industries Thermal Systems
Supply temperature	120–150°C (steam)	150°C (steam)	80°Cin / 180°Cout	70°Cin / 160°Cout	100°Cin / 200°Cout
Heat source temperature	60–90°C	80°C	80°C	80°C	95°C
Heating capacity	30 kW	260 kW	500 kW	600 kW	600 kW
Refrigerant	R1336mzz(Z)	R601	R600 or HFO	R1336mzz(Z)	HFE356mmZ
Compressor	Scroll	Screw	Centrifugal	Centrifugal	Centrifugal

2.2. Market status

The market status of industrial heat pumps in Japan is reflected in two statistics, as shown in Table 2. The first statistic is an annual publication by the Ministry of Environment (MOE) that tracks progress on the Plan for Global Warming Countermeasures [7], which was established by the Japanese Cabinet in May 2016. This report describes the cumulative heating capacity of installed industrial heat pumps and is based on surveys

conducted by the Ministry of Economy, Trade, and Industry (METI) and the Japan Refrigeration and Air Conditioning Industry Association (JRAIA). Although the data are limited to products from seven suppliers and do not represent the whole market, they are used as a policy indicator, and it is pertinent to monitor their progress.

The second statistic, published annually by the Japan Electro-Heat Center (JEHC) [8], is used as a basic material for the promotion of industrial heat pumps. This report covers a wider range of suppliers and their products, including MVR systems. In addition to the total heating capacity, the report also provides information on the capacity and number of units in the heat pump category, as well as information on the industries and processes in which heat pumps have been installed.

Table 2. Two statistics on the market status of industrial heat pumps in Japan [7, 8]

Publication	MOE (Ministry of Environment)	JEHC (Japan Electro-Heat Center)
Surveyed organization	METI (Ministry of Economy, Trade, and Industry) and JRAIA (Japan Refrigeration and Air Conditioning Industry Association)	JEHC and Fuji Keizai
Purpose	Policy indicator	Basic material for promotion
Coverage	7 suppliers	24 suppliers
Items	• Total capacity	• The capacity and number of units for each heat pump category • Installed industries and processes

Figure 3 shows the cumulative heating capacity of industrial heat pumps, as reported by the MOE. The Japanese government expects that the total capacity will reach 1,673 MW in FY2030. However, the actual installation in FY2020 was 168.4 MW, indicating a need to accelerate the installation.

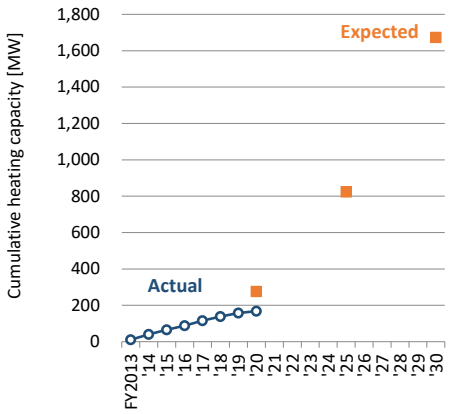

Fig. 3. The policy indicator and actual cumulative heating capacity of industrial heat pumps in Japan [7].

Figure 4 shows the entire installation of industrial heat pumps, as documented by the JEHC. As of FY2020, the cumulative capacity of closed-system heat pumps stands at 877 MW, while that of open-type heat pumps (MVRs) is 440 MW, totaling 1,317 MW. The actual installation is approximately 7.8 times greater than the data used in the government's policy indicator. The cumulative number of installed MVRs was 248, with a total heating capacity of 440 MW and an average unit capacity of 1.8 MW. Conversely, for air-source hot water heating heat pumps, although 981 units are installed, the average unit capacity is 24 kW. The demand for industrial heat pumps with a broad range of capacities remains evident.

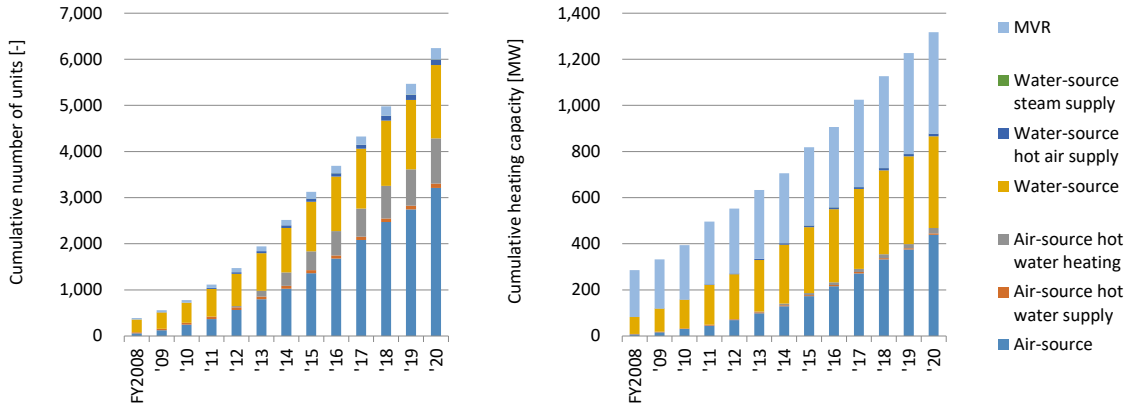

Fig. 4. The entire installations of industrial heat pumps in Japan [8].

For closed-system heat pumps, the breakdown of the installed industries is shown in Fig. 5. The machinery industry, including the automobile and electronics industries, demonstrates the highest installation density. This distribution pattern reflects the prevalent orientation of the Japanese industrial landscape towards machinery development.

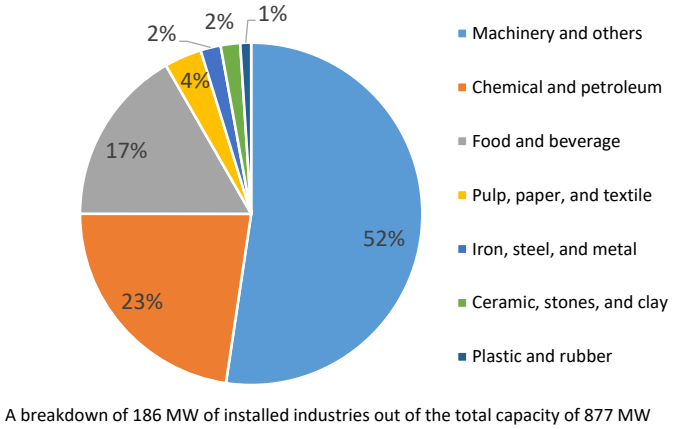

Fig. 5. Installed industries for closed-system industrial heat pumps in Japan [8].

2.3. Summary of the current status

In Japan, various types of industrial heat pumps with a wide range of specifications have been commercialized, largely due to the support provided by the government and electric utilities towards heat pump manufacturers in their developmental endeavors. Industrial heat pumps are considered to have achieved a high level of technological maturity. However, the rate of adoption has not progressed as anticipated. To foster widespread adoption, it is imperative to mitigate not only technological impediments, but also economic and site-specific obstacles.

3. Barrier Analysis

This chapter presents the results of a questionnaire survey of industries, clarifies why the installation of industrial heat pumps has not progressed, and discusses future measures.

3.1. Questionnaire survey

The authors conducted a questionnaire survey regarding the current status of decarbonization efforts in the manufacturing industry and the adoption of industrial electrification technologies, including heat pumps,

resistance heating, induction heating, dielectric heating, infrared heating and arc furnace. In this paper, we introduce extracts related to industrial heat pumps.

This survey was conducted by mail. The response period was from October 15 to November 5, 2021. This survey covered factories in which energy management was specified in the Energy Efficiency Act. Out of the 6,016 mailed questionnaires, there were 690 valid responses, yielding a response rate of 11.5%. This study provides answers to the following questions:

- Q1. Are you currently planning or making progress towards decarbonization in your factory?
- Q2. Are you currently planning or making progress towards electrification?
- Q3. What specific decarbonization efforts are you taking?
- Q4. Have you installed heat pumps in your factory yet?
- Q5. Are you satisfied with your heat pumps?
- Q6. Are you satisfied with your heating equipment?
- Q7. Do you plan to install heat pumps in your factory in the near future?
- Q8. What reasons are making you reluctant to install heat pumps?

Questions one to three are about the status of the efforts towards decarbonization. The survey responses from 671 companies, as depicted in Fig. 6, reveal that 29% of the companies have already initiated efforts towards decarbonization and 47% are in the planning stage. However, 25% of the companies have yet to begin planning for decarbonization. Companies with fewer employees were noted to be less active. The same trend was observed for electrification. Of the companies that have either initiated or are planning for decarbonization, 90% reported that improving energy efficiency was a specific action, as depicted in Fig. 7. Energy efficiency improvement is directly linked to energy cost reduction, which explains its high priority. On the other hand, only 17% of the companies have adopted electrification as a specific action, as it does not guarantee energy cost reduction at present.

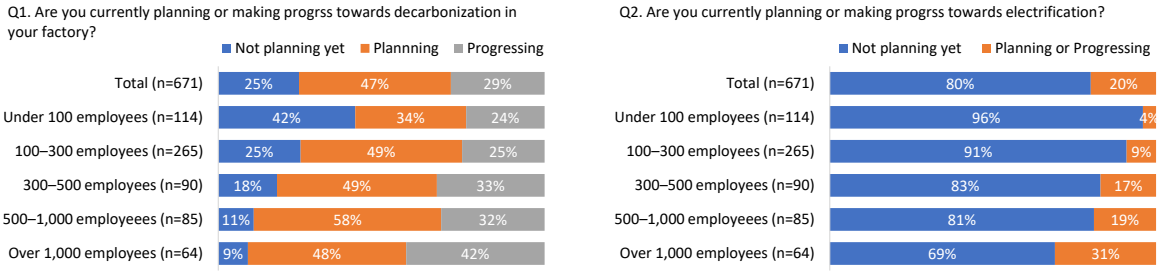

Fig. 6. Questionnaire for decarbonization and electrification.

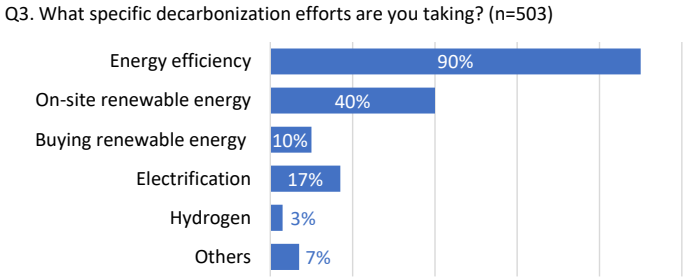

Fig. 7. Questionnaire for specific efforts toward decarbonization.

A heat pump is a technology that can simultaneously improve energy efficiency and electrification. Figure 8 shows the status of industrial heat pump installations, which encompasses both relatively low-temperature heat pumps, such as air conditioning in clean rooms, as well as high-temperature heat pumps. Of the 476 companies that responded, 38% have already installed heat pumps, while 48% acknowledge their importance but have yet to install them. Moreover, 13% of the companies do not recognize the value of heat pumps.

Of the 155 companies that have already installed heat pumps, 89% reported satisfaction with their performance. Figure 9 shows a comparison of satisfaction with heat pumps and combustion equipment, demonstrating that heat pumps are on par with combustion steam boilers and water heaters in terms of user

satisfaction. Despite any initial concerns that companies may have had prior to the installation of heat pumps, the survey results indicate a high degree of satisfaction post-installation.

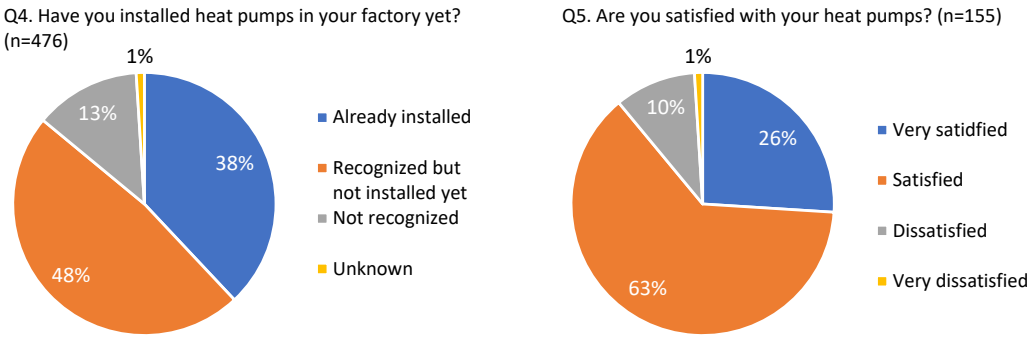

Fig. 8. Questionnaire for installation of and satisfaction with heat pumps.

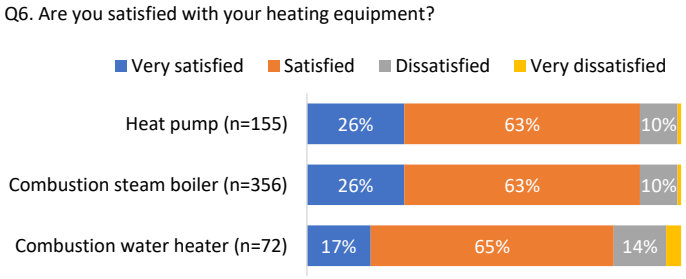

Fig. 9. Questionnaire for satisfaction with heat pumps compared to boilers.

Figure 10 shows the responses to the question regarding the future plans for the introduction of heat pumps. Of the 126 companies that have already partially installed heat pumps, 30% are planning new installations, and 32% are contemplating such installations. Conversely, only 4% of the companies that have not yet installed heat pumps are planning to do so. Therefore, it appears that prior experience with heat pump installations may facilitate further adoption.

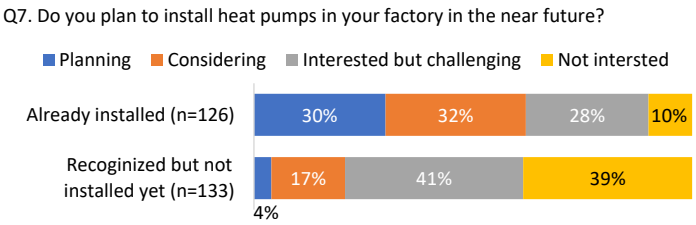

Fig. 10. Questionnaire for those having the intention to install heat pumps in the near future.

As shown in Fig. 10, many companies, 28% of those that have already partially installed and 41% of those that have recognized the importance of heat pumps but have not yet installed them, answered that they were interested in heat pumps but found the installation process challenging. Figure 11 sheds light on the reasons behind their reluctance to install heat pumps, with most of these companies not being concerned with the technological maturity, energy efficiency, or CO_2 reduction capabilities of heat pumps. Nonetheless, there are technological considerations other than heat pump equipment that may be impediments to the widespread introduction of heat pumps.

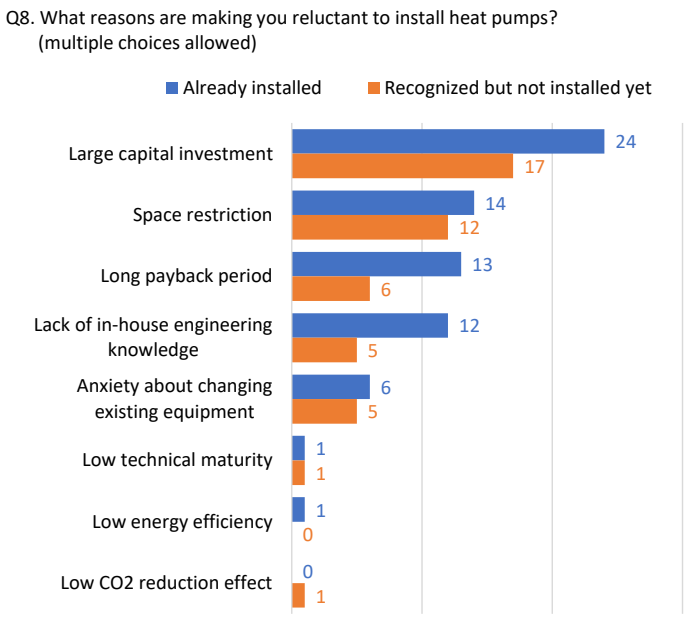

Fig. 11. Questionnaire showing the reasons for the reluctance to install heat pumps.

The major impediments to the widespread adoption of heat pump technology are primarily of an economic and financial nature. Companies are concerned about large capital investments and extended payback periods. Interestingly, some companies are only concerned about large capital investments; others have complaints about the payback period. These findings suggest that the introduction of more favorable financing arrangements could help to overcome these barriers.

Moreover, site-specific factors, such as the lack of installation space or in-house engineering expertise, were also identified as key challenges by some companies. Some existing factories may not have enough space to install heat pumps, especially when considering the recovery of waste heat from heating processes. In addition, some companies lack in-house engineering capabilities, thereby making it challenging for them to assess the benefits and feasibility of heat pump adoption.

3.2. Barriers and solutions

So far, the support for industrial heat pumps by the Japanese government has mainly focused on technological developments, such as the development of high-temperature heat pumps. These supports have successfully improved the technical potential and maturity of the industrial heat pumps. Nevertheless, it is imperative to continue to support the development of low-GWP refrigerants as well as related lubricants, oils, and compressors. However, for the widespread adoption of industrial heat pumps, it is crucial to extend support beyond heat pump equipment technology in the future.

Table 3 summarizes the main barriers and possible solutions for industrial heat pump applications. As for the solutions, while there may be a number of measures that private entities can undertake voluntarily, this table only considers the solutions that the government can implement.

The installation of a heat pump system requires a thorough analysis of the sources of heat and the areas in which it needs to be supplied. Therefore, it is necessary to establish a process integration methodology and to conduct research on technology deployment as well as technology development.

To provide support in terms of capital expenditure (CapEx), it would be effective to focus on small and medium-sized enterprises (SMEs) and new factories. Additionally, in terms of operating expenses (OpEx), rebalancing the renewable energy levy can be a fair and effective measure.

Table 3. Main barriers and possible solutions for widespread adoptions of industrial heat pumps in Japan

Barrier	Current status	Possible Solution (by the government)
High capital investment	• Companies with fewer employees are challenged to initiate efforts toward decarbonization.	• It is necessary to support capital investment, mainly targeting small and medium-sized enterprises (SMEs).
Long payback period	• Electricity price is relatively expensive compared to fuel prices. One of the factors is that renewable energy levy is imposed only on electricity.	• Rebalancing the renewable energy levy can be a fair and effective measure.
Space restriction	• It is difficult to address the lack of installation space in existing factories.	• It would be useful to take measures to encourage the introduction of industrial heat pumps in new factories.
Lack of in-house engineering knowledge	• Many companies lack the necessary knowledge and skills to integrate heat pumps into their processes or utilities.	• It is necessary to strengthen the demonstration and deployment projects for the purpose of establishing process integration methodology and to cultivate process integrators.

4. Conclusions

The integration of industrial heat pumps is deemed crucial for decarbonization. Despite the advancements and commercialization of various types of industrial heat pumps in Japan, their widespread adoption has not materialized as anticipated.

To gain a deeper understanding of the barriers hindering the implementation of industrial heat pumps, a questionnaire survey was conducted. The results highlight four main barriers: high capital investment, a long payback period, spatial restrictions, and a lack of in-house engineering expertise. In addition, we listed the possible solutions that can be provided by the government for each barrier.

These barriers are believed to be common worldwide, and it is our aim to contribute to overcoming these obstacles by sharing our findings and insights with other countries and promoting the utilization of industrial heat pumps globally.

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