Industrial Heat Pumps, Second Phase

IEA Heat Pump Programme Annex 48

Task 1:
Headline

Prepared by
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Contents

1 Introduction

Japan has relied on overseas fossil fuels for approximately 90 % of its total energy supply in 2017. High dependence on fossil fuels influences on ensuring energy security as well as measuring environmental issues such as air pollution and global warming. In particular, a global warming problem enhances world-wide activities to measure anthropogenic greenhouse gas (GHG) emissions.

According to the Synthesis Report published by the Intergovernmental Panel on Climate Change (IPCC) in November 2014, there is a requirement to reduce substantial amounts of GHG over the next few decades and attain near zero emissions of GHG by the end of the century in order to maintain global warming likely below 2 °C.

In November 2016, United Nations Framework Convention on Climate Change (UNFCCC) members ratified the Paris Agreement which sets a globally agreed target of limiting future temperature increases to “well below 2 °C” above pre-industrial levels and “pursuing efforts to limit the temperature increase to 1.5 °C above pre-industrial levels.” In the Agreement, each country determines, plans, and regularly reports its own contribution it intends to achieve in order to mitigate global warming.

The government of Japan approved the Plan for Global Warming Countermeasures in May 2016, which sets the target of 26% GHG reduction by 2030 and also aims to reduce GHG emissions by 80% by 2050 as a long-term goal. To achieve this target, Japan plans to aggressively promote energy conservation measures and de-carbonization measures on both supply and demand sides.

Among the various measures of energy conservation, a heat pump is one of the promising technologies to improve energy efficiency as well as to mitigate GHG emissions. A heat pump is a system that can transfer heat from a low-temperature zone to a high-temperature zone, consuming only a small amount of motive power by means of a change in state such as the pressure and temperature of a heating medium. Heat pump technologies have become increasingly important in the world. The heat pump market has been increasing in conjunction with the increasing use of air conditioning and hot water supply appliances in residential and commercial buildings.

However, in the industrial field, the actual application of the heat pump is limited in spite of its possessing large market potential with a large amount of heat consumption. To further enhance energy conservation and GHG mitigations, it is expected that heat pump applications will be promoted for industrial sector. Industrial heat pumps (IHPs) offer various opportunities to all types of manufacturing processes and operations. They use waste process heat as the heat source, delivering heat at higher temperatures for use in industrial processes, heating or preheating, and industrial space heating and cooling. IHPs can significantly reduce fossil fuel consumption and GHG emissions in a variety of applications, such as drying, washing, evaporation, and distillation processes. Industries that can benefit from this technology extend over a wide field such as food and beverage processing, forest products, textiles, and chemicals.

The IEA HPT-IETS Annex 35/13 “Application of industrial Heat Pumps” (2010–2014) has been a joint venture of the International Energy Agency (IEA) Implementing Agreements “Heat Pumping Technologies (HPT)” and “Industrial Energy-Related Technologies and Systems (IETS).” The aim is to understand the worldwide activities of industrial heat pumps which have been to actively contribute to the reduction of energy consumption and GHG emissions through the increased utilization of heat pumps in industry. The program and work of Annex 35 have mainly concentrated on the collection of statistical energy and environmental data and technological information on IHPs, as well as the present status of R&D and the application of heat pumps in industry. A total of 39 R&D projects and 115 applications of heat pumps in industry, in particular the use of waste process heat as the heat source, have been presented and analyzed by the participating countries.

Considering the results of Annex 35/13, the number of application samples is insufficient to understand the best practice of heat pump technology and its application in industrial processes used for heating, ventilation, drying, dehumidification, and other purposes. The follow-up annex is required to fill up a heat pump database that is useful for stakeholders in selecting the best practice.

Annex 48 was established in 2016 as a follow-up annex from the previously completed Annex 35/13. The goal of the new annex is to concentrate on the development and distribution of condensed and clear informational materials for policy makers, associations, and industries.
The activities of Annex 48 are structured by four different tasks. The legal text of each task is decided by members of participating countries as follows:

(1) Task 1; Analysis of the collected case studies and successful applications of industrial heat pumps
   - To select excellent application opportunities, successful applications, and approved examples
   - To select a limited number of industries with large potential, focused on special areas with high product quality

(2) Task 2; Structuring information on industrial heat pumps and preparation of guidelines
   - A heat pump database to be used for structuring information obtained from Task 1 for each industry with the best available technologies and best practices

(3) Task 3; Application of existing models for the integration of a heat pump into a process
   - OSMOSE integration tool for the integration of heat pumps into industrial processes (EPFL University Lausanne)
   - CERES, a strategy for the recovery and reuse of waste heat in industrial processes

(4) Task 4; Communication of the IHP potential for policy makers, designers and decision makers
   - Arranging the information on heat pumping technologies for policymakers, etc.
   - Providing a better understanding of the opportunities for energy conservation, CO_2 emissions as well as the economy
   - Developing marketing and communication instruments and potentially support and advise legislators.

As for Task 1, it is needed to develop an analytical matrix which structures information on IHP applications to select excellent application opportunities. The framework of information is provided and integrated based on the good practices of IHP applications. In the case of Japan, around 100 good practices have been collected as samples for the Annex 35/13 report and new investigation of Annex 48. They are generalized and classified into the matrix. The matrix is also analyzed to understand the present status of IHP applications and to select the best practice among the samples.

2 Industrial Heat Demand

2.1 Definition of Industrial Heat Pump

The definition of industrial heat pump was agreed to at the kick-off meeting held in May 2016 as follows; "Heat pumps in the medium and high-power range and temperatures up to 200 °C, which can be used for heat recovery and heat upgrading in industrial processes, as well as for heating, cooling, and air-conditioning in commercial and industrial buildings."

The industry covers industrial sectors to produce goods such as agriculture/forest/fishery, mining/stone/ gravel/construction work and manufacturing industries, as well as service sectors to provide multiple services for customers. The manufacturing industry, especially material production industries like iron and steel, chemical and allied products, ceramic/stone/clay products, and pulp/paper/paper products is energy intensive, consuming a large amount of energy per product. On the other hand, the energy intensity of service industries is estimated low. They comprise office buildings, finance and insurance, wholesalers, eating and drinking services, hotels and inns, education and scientific research organizations, hospitals and clinics, amusement facilities, etc.

2.2 Industrial Heat Demand and Market Potential of IHPs

The final energy demand of the manufacturing industry accounts for 43% of a total demand in Japan in 2016FY following 23% of transportation, 16% of commercial, 14% of residential and 3% of agriculture/fishery/construction sectors. The material production industries, namely iron and steel, chemical and allied products, ceramic/stone/clay products, and pulp/paper/paper products, account for 71% of the final energy consumption of the manufacturing industry as a whole.

Energy for the manufacturing industry is consumed for different types of energy use. Figure 1-1 shows different types of energy use such as fossil fuels used for direct heating, electricity, auto steam generation, and renewable and recovered energy.

Fossil fuels such as oil products, town gas, and coal products are used for the direct heat needed for process heating in industry. The demand for direct heat is the largest, accounting for 63% of the total industrial demand, followed by electricity at 28%, auto steam generation at 8.5%, and renewable and recovered energy at 0.3%. Focusing on heat demand for direct heat and auto steam generation in industry, share of direct heating achieves by 88%.

Direct heat generates heat at a high level of temperature exceeding 150 °C. It is consumed mainly in chemical and allied products, and iron and steel sectors. Auto steam generation is produced by a boiler at a temperature level below 150 °C. Fuels used for the generation are supplied by 70% fossil fuels and 30% renewable energy. Input fuels into the boiler generate approximately 20% of heat loss in boiler combustion. The final energy consumption of auto steam generation is estimated to be 744,900 TJ in 2015 FY.

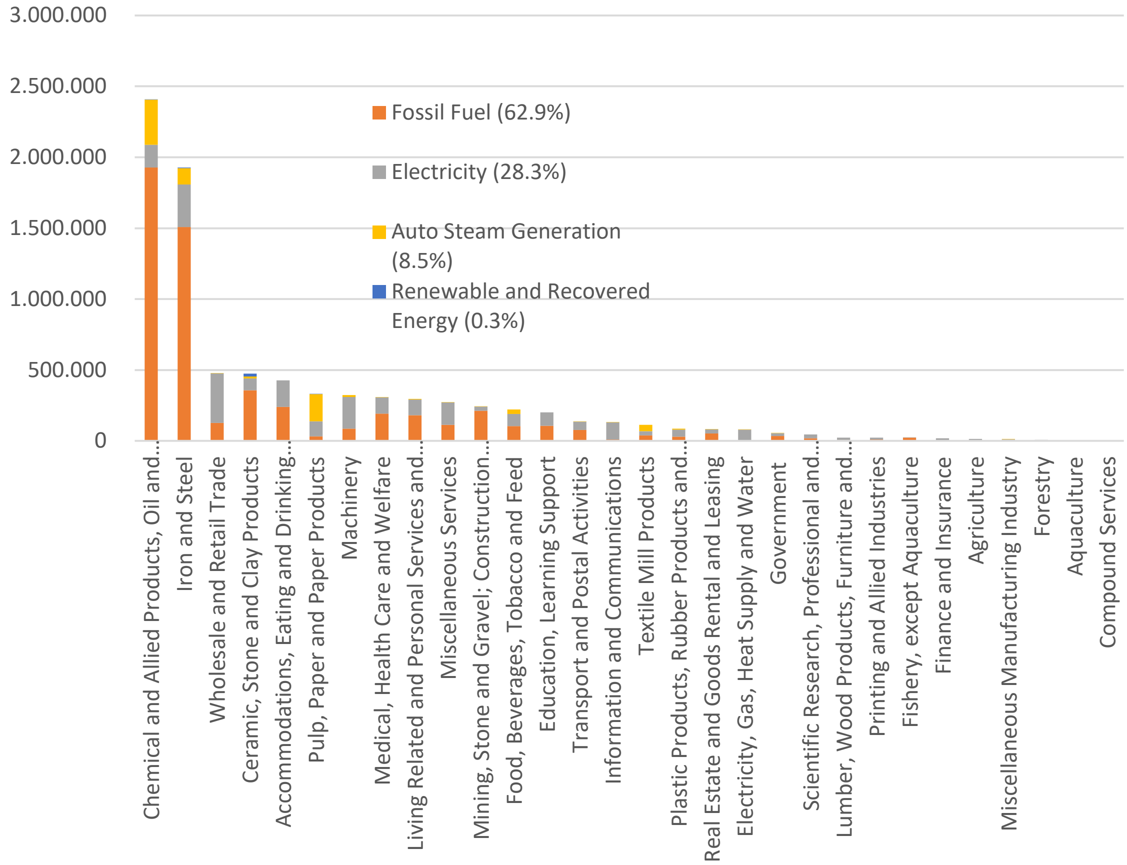
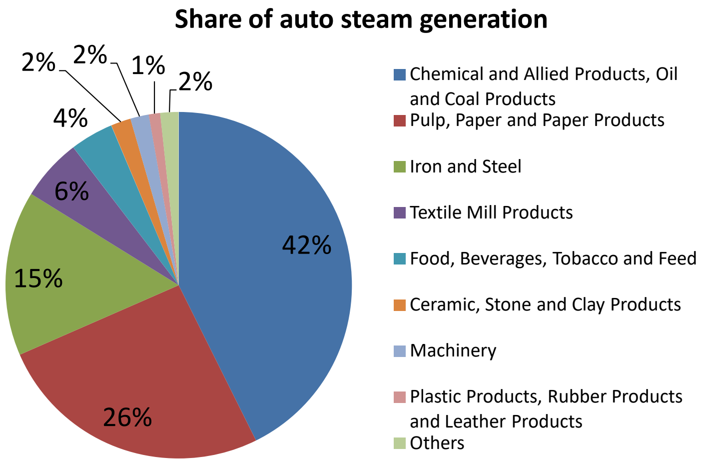


Figure 1-1: Final energy consumption of industrial sectors in 2015 FY) (TJ) [METI, 2014]

Figure 1-2 shows rates of final energy consumption for auto steam generation in different sectors and the distribution of steam temperature levels in 20 different industries. Chemical and allied products and pulp/paper/paper products are predominant sectors that consume auto steam generation at nearly 70% of the total demand. Consumption rates of iron and steel, textile mill products, food / beverages / tobacco, and feed follow in that order. The temperature level of auto steam generation is lower than that of direct heating. High temperature IHPs are expected to be widely applied in the field of auto steam generation, bringing about energy conservation and CO_2 emission reduction.



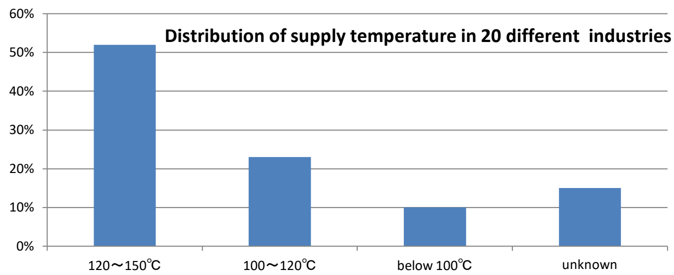


Figure 1-2: Rates of auto steam production industries and distribution of supply temperature in 20 different sectors in 2015 FY.

Heat demands in both direct heat and auto steam generation are indicated in Table 1-1. The heat demands of industrial sectors which installed IHPs in the past are estimated to be rather large, accounting for 70% of direct heat and 95% of auto steam generation. However, the market potential of IHPs seems to be limited in the field of direct heat used for process heating, because the temperature level of process heating is rather high at over 150 °C. IHPs are expected to be installed in the auto steam generation field where heat is used at a lower temperature level below 150 °C. It is promising that in the future the market for IHPs will increase in the fields of chemical and allied products, pulp/paper/paper products, iron and steel, textile mill products, and food and beverages.

Table 1-1: Potential heat demand for different industries [METI, 2014]

Industry	Direct heating (TJ)	Auto steam generation (TJ)
Chemical and allied products	1,927,446 (35%)	317,616 (43%)
Iron and steel	1,506,880 (27%)	114,377 (15%)
Pulp/paper/paper products	32,730 (0.6%)	192,282 (26%)
Food/beverages	104,441 (2%)	30,000 (4%)
Agriculture/forest/fishery	41,457 (0.8%)	37 (0%)
Machinery	86,166 (1.6%)	12,820 (2%)
Electronics/information and communication	121,433 (2.2%)	212 (0%)
Textile mill products	37,954 (0.7%)	43,234 (6%)
Others	1,658,497 (30%)	34,342 (5%)

（）: rates of heat demand

3 Merits of IHPs and Industrial Applications in Japan

3.1 Merits of IHPs

Fossil fuels are widely used to generate high temperature gas and steam in various industrial heat supply processes. Steam generated by a boiler in the energy center is delivered to all areas of the factory for use in the manufacturing process. A demerit of the conventional heat systems supplied by boilers is the generation of heat losses such as boiler combustion losses, heat losses from piping, and drain recovery losses. Figure 1-3 shows an average value for heat losses obtained from 29 samples in conventional boiler systems. Heat losses are generated in boiler combustion at 10%, piping at 25%, and drain recovery at 10%. Net heat utilization is limited by only 55% of the total primary energy.

Boilers have been supplying high-temperature steam at temperatures of 120 °C or more for applications such as sterilization, concentration, drying, and distillation. However, in recent years, high-temperature steam in excess of 120 °C can now be supplied by a heat pump. A heat pump is a system that can transfer heat from a low-temperature zone to a high-temperature zone. It is essentially a heat engine operating in reverse, consuming only a small amount of motive power by means of a change in state such as the pressure and temperature of a heating medium (refrigerant). The technological performance of a heat pump is characterized by a coefficient of performance (COP). Heating supplied by a heat pump can be performed at higher efficiency than that achieved by the conventional boilers with fossil fuels. The COP has been increasing during the past three decades with technological advances achieved by an inverter, highly efficient compressor and heat exchanger, and a new refrigerant.

Significant energy savings are expected by replacing steam supply systems with distributed high-temperature heat pumps for hot water, hot air supply, and heating of circulating hot water generation. For example, a high-temperature heat pump with a COP of 3 to 5 could save 50 to 70% of the primary energy in comparison with the boiler steam supply system (Figure 1-3).

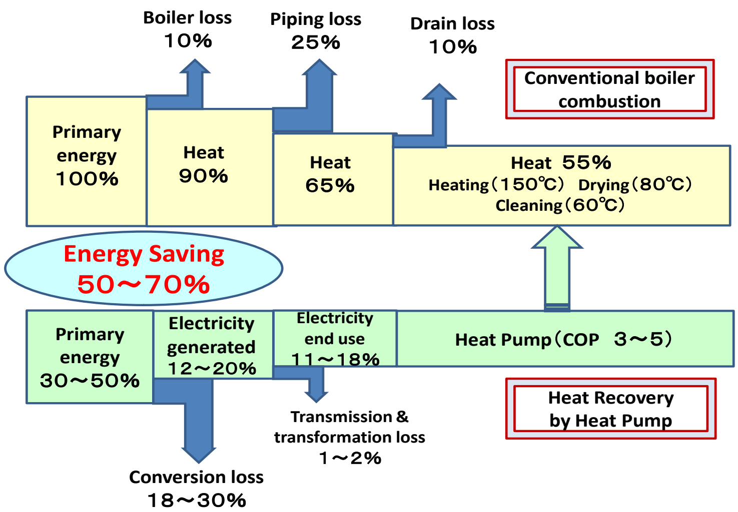


Figure 1-3: Advantage of IHP in comparison with conventional fossil fuel combustion boiler

Heat losses of the boiler system in Figure 1-3 consist of boiler combustion loss, piping loss, and drain loss. Steam delivered to production processes is utilized as various process heats for heating, drying, washing, sterilization, concentration, drying, distillation, etc. In the process heat utilization stages, various exergy losses are generated in addition to the boiler system losses. Actual heat losses are estimated by the larger amount of value.

3.2 Industrial Applications in Japan

Heat pumps with operating temperatures below 100 °C are widely used in many cases. However, heat pumps with higher operating temperatures above 100 °C are required to develop R&D activities such as high temperature technologies, integration of heat pumps into industrial processes, and environmentally sound refrigerants.

A large number of industrial heat pumps have been installed in the foodstuff industry, and more application is expected in the industry. The temperature level ranges from 60 to 100 °C in the foodstuff industry, and current heat pump technologies can be applied for this temperature range. Additionally, heat demands for typical foodstuff manufacturing lines are mixed with cold and hot heat, realizing the utilization of simultaneous heating/cooling systems for both forms of heat available from heat pumps. The use of heat pumps is also expanding in the drying process field. Heat pumps are installed before existing equipment for heating and drying, using waste heat as an energy conservation measure for existing drying equipment in painting, printing, and fluidized-bed drying processes.

Table 1-2 lists appropriate temperature levels applied for heating and cooling in different industrial sectors and processes. In the food industry, heat pump is applied to cooling and heating processes at a lower temperature level. The lowest temperature is minus 60 °C for freezing foods. The highest temperature is approximately 80 °C for sterilization in milk and ham production. The temperature level in an agricultural industry is approximately 60 °C. Textile, lumber and woods, pulp and paper, and the chemical industry need a higher temperature for drying, concentration, dehumidifying, distillation, and refinery processes as shown in the table.

Table 1-2: Temperature levels for heating/cooling applications in sectors and processes of industries [JEHC,2016]

	Examples of thermal process	Temperature level [°C]
Foods production	Freezing foods	-60 ~ -30
Foods production	Cooling of chicken	-20 ~ 5
Foods production	Cooling of noodle	1 ~ 3
Foods production	Sterilization and cooling of milk	3 ~ 5 70 ~ 75
Foods production	Ham production	2 ~ 80
Foods production	Retort pouch	3 ~ 5 70 ~ 75
Foods production	Fermentation of Japanese sake	14 ~ 15
Foods production	Fermentation and temperature control of wine	16 ~ 20
Foods production	Seaweed drying	20 ~ 30
Foods production	Temperature control of yeasts and bread	22 ~ 30
Foods production	Fermentation of miso & shoyu	27 ~ 28 38 ~ 40
Foods production	Rice koji drying	35
agriculture	Low temperature storage	1 ~ 6
agriculture	Pre-cooling	3 ~ 5
agriculture	Cooling and washing for milking process	0 ~ 4 40 ~ 60
agriculture	Mushroom cultivation	13 ~ 20
agriculture	Temperature control for slop culture	15 ~ 25
agriculture	Greenhouse cultivation	18 ~ 32
agriculture	Dehumidifier cultivation	20 ~ 23
agriculture	Heating for stock breading	20 ~ 30
agriculture	Egg incubation	36 ~ 38

	Examples of thermal process	Temperature level [°C]
forestry	Lumber dehumidifier	40 ~ 60
Wholesale trade	Freezing exhibit case	-20 ~ -10
Wholesale trade	Cooling vehicle	-10 ~ 0
Wholesale trade	Hot water sully for cooking room	60 ~ 80
services	Heating for indoor pool water	~ 35
services	Heating for hot spring	~ 60
services	Hot water supply for bathhouse	50 ~ 65
Textile industry	Dry cleaning	20 ~ 30
Textile industry	Cloth drying	60 ~ 80
Textile industry	Dyeing heating	90
Textile industry	Towel dyeing	~ 100
Lumber &	Drying of furniture and musical instr.	38 ~ 60
Pulp, paper,	Drying of paper and pulp	80 ~ 130
Chemical industry and petro-refinery	Concentration of medicine	20 ~ 60
Chemical industry and petro-refinery	Dehumidifying of incense stick	25 ~ 30
Chemical industry and petro-refinery	Separation and synthesis of petro.	60 ~ 120
Chemical industry and petro-refinery	Petroleum refinery	60 ~ 180
Chemical industry and petro-refinery	Distillation of chemicals	80 ~ 170
Waste control	Dehydration of dirty mud	~ 60

3.3 Industrial Heat Pump Technologies

Industrial heat pumps are active heat recovery devices which use waste process heat as the heat source and deliver heat at higher temperatures for the heat sink in industrial processes, heating or preheating, or for space heating and cooling in industry. They can provide active characteristics of energy conservation which cannot be achieved with the conventional system of passive heat recovery.

The source and sink temperatures determine which IHP types can be used in a specific application. These types can be categorized in various ways such as mechanically- or heat-driven, compression or absorption, and closed or open cycles.

The most important processes for industrial heat pumps are categorized by the work driven by heat pumps as follows;

- Closed compression cycle : electric driven type with motor, engine driven type with gas engine
- Recompression cycle: mechanical vapor recompression (MVR), thermal vapor recompression (TVR)
- Thermal compression cycle : absorption heat pumps, absorption-compression cycle
- Current development: thermos-acoustic type, active magnetic regenerator

3.3.1 Closed compression cycle (mechanical compression cycle)

3.3.1.1 Electric driven type with motor

Working fluid such as a refrigerant is compressed by a motor-driven compressor. Heat generated by compression is utilized for the general purpose of heating or drying. The low temperature heat of the working fluid gas generated to be expanded by an expansion valve is utilized for the cooling gas of air conditioning. Figure 1-4 shows the working principle of the electric driven heat pump.

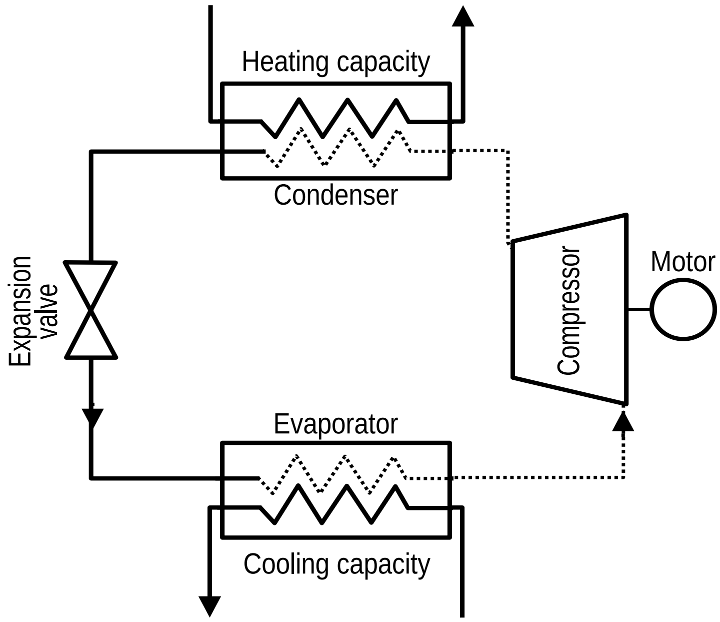


Figure 1-4: Electric driven type with motor

Four different types of compressors are used in closed compression cycle heat pumps: scroll, reciprocating, screw, and turbo. Scroll compressors are used in small and medium-sized heat pumps up to 100 kW heat output, reciprocating compressors in systems up to approximately 500 kW, screw compressors up to approximately 5 MW, and turbo compressors (centrifugal compressors) in large systems above approximately 2 MW, as well as oil-free turbo compressors above 250 kW.

3.3.1.2 Engine driven type with gas-engine

The system utilizes gas-engine, diesel-engine, steam turbine, and gas turbine as a driven machine instead of a motor. The investment cost of equipment is more expensive than the motor driven type, but high heating efficiency is obtained by utilizing available wasted heat generated by an engine.

3.3.2 Recompression cycle

3.3.2.1 Mechanical vapor recompression

MVR is the technique of increasing the pressure, thus also increasing the temperature of waste gases, thereby allowing their heat to be re-used. The most common type of vapor compressed by MVR is steam which is referred to in Figure 1-5 below. There are several possible system configurations. The most common is a semi-open type in which the vapor is compressed directly (also referred to as a direct system). After compression, the vapor condenses in a heat exchanger where heat is delivered to the heat sink. This type of MVR system is very common in evaporation applications.

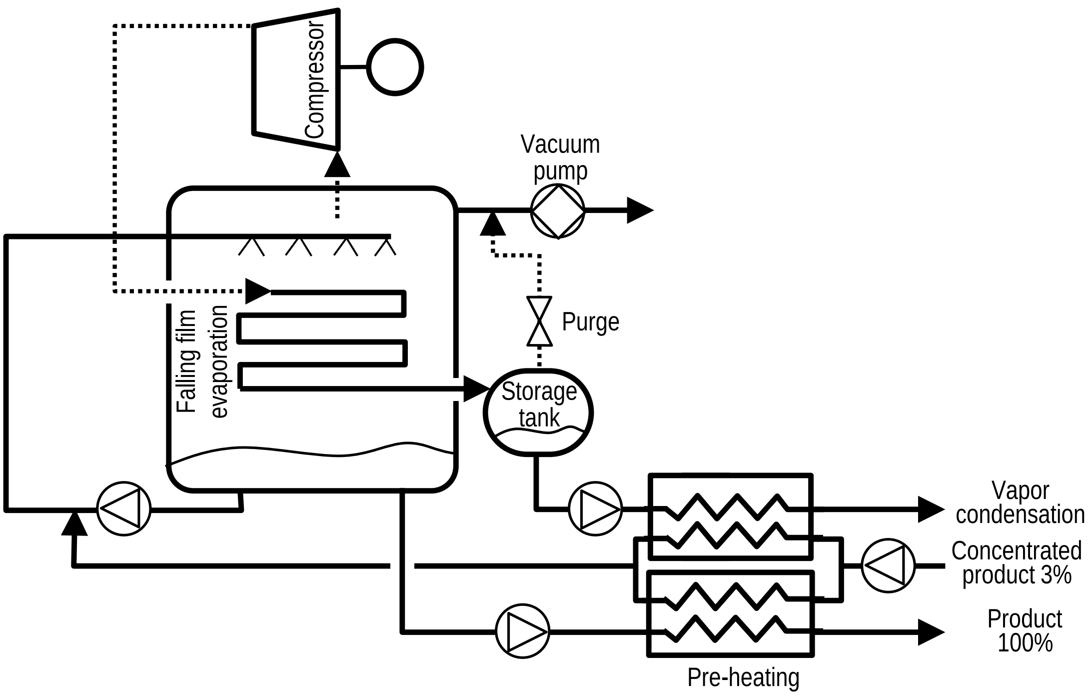


Figure 1-5: Mechanical vapour recompression

The other type of semi-open system lacks the condenser, but it is equipped with an evaporator. This less common configuration can be used to vaporize a process flow that is required at a higher temperature, with the aid of mechanical work and a heat source of lower temperature. In the case of direct compression of a solvent, it is necessary to take measures to protect against corrosion and to fully clean away extraneous matter like scale.

3.3.2.2 Thermal vapour recompression

With the TVR type of system, heat pumping is achieved with the aid of an ejector and high-pressure vapour. It is therefore often simply called an ejector. The principle is shown in Figure 1-6 below. Unlike the MVR system, a TVR heat pump is driven by heat, not mechanical energy. Thus, compared to an MVR system, it opens up new application areas, especially in situations where there is a large difference between fuel and electricity prices.

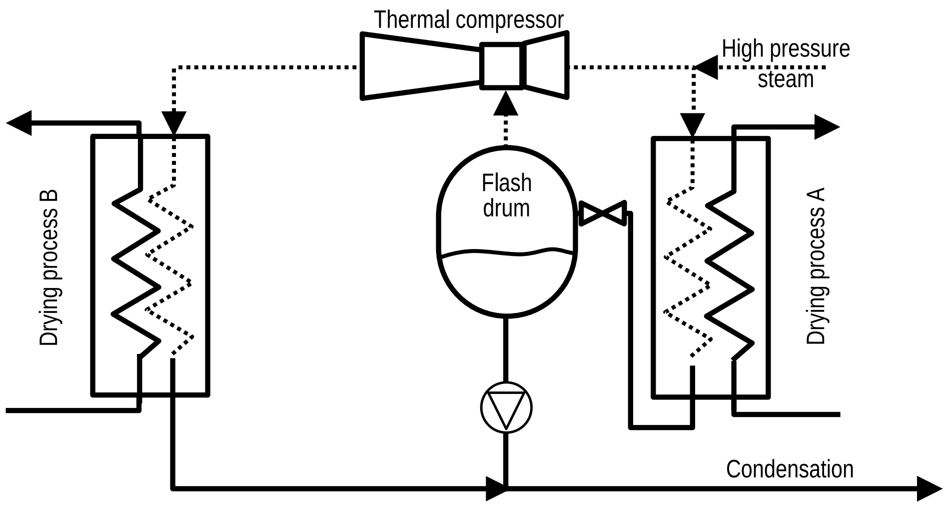


Figure 1-6: Example of thermal vapour recompression

The TVR type is available in all industrial sizes. A common application area is evaporation units. The COP is defined as the relation between the heat of condensation of the vapour leaving the TVR and heat input with the motive vapour.

3.3.3 Thermal compression cycle

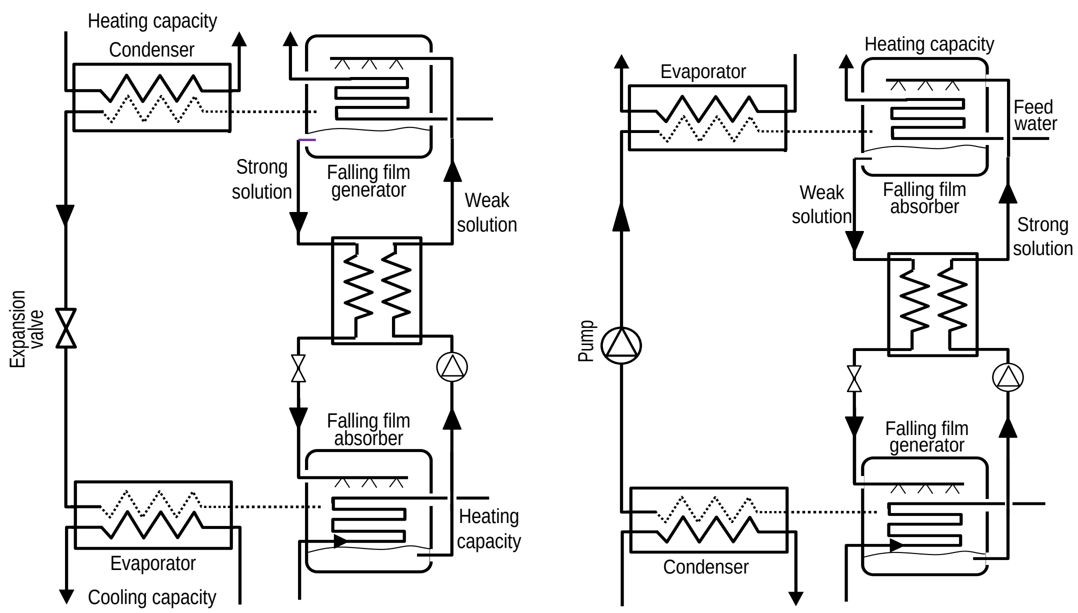
3.3.3.1 Absorption heat pumps

Absorption heat pump cycles are based on the fact that the boiling point for a mixture is higher than the corresponding boiling point of a pure, volatile working fluid. Thus, the working fluid must be a mixture consisting of a volatile component and a non-volatile component. The most common mixture in industrial applications is a lithium bromide solution in water ($LiBr/H_2O$) and ammonia water (NH_3/H_2O).

The fundamental absorption cycle has two possible configurations: absorption heat amplifier (AHP) Type I and AHP Type II, which are suitable for different purposes. The difference between the cycles is the pressure level in the four main heat exchangers (evaporator, absorber, desorber, and condenser), which influence the temperature levels of the heat flows.
The first type of absorption heat pump (the absorption heat amplifier cycle) obtains heat from a driving heat source, as well as heat drawn from a low-temperature heat source, and discharges it to a high-temperature heat source as shown in Figure 1-7 (a). The amount of heat discharged to the high-temperature heat source exceeds that of the driving heat source. How-

ever, the temperature of the high-temperature heat source is lower than that of the driving heat source.

The second type of AHP (the absorption heat transformer cycle) draws heat to a high-temperature heat source while discharging some of the heat obtained from a driving heat source to a low-temperature heat source as shown in Figure 1-7 (b). The amount of heat discharged to the high-temperature heat source is less than that of the driving heat source. Despite this, the temperature of the high-temperature heat source is higher than that of the driving heat source.



(a) Absorption heat amplifier cycle (b) Absorption heat transformer cycle

Figure 1-7: Thermal compression cycle (Absorption heat pump)

3.3.3.2 Absorption-compression hybrid

The hybrid heat pump combines substantial parts of both absorption and compression machines; it utilizes a mixture of absorbent, refrigerant, and a compressor as shown in Figure 1-8. An important difference between the hybrid and absorption cycle should be noted; the absorber and desorber in the hybrid heat pump are placed in a reversed order from that in the absorption machine, i.e., desorption in the hybrid cycle occurs under low temperatures and pressures, and absorption occurs under high temperatures and pressures.

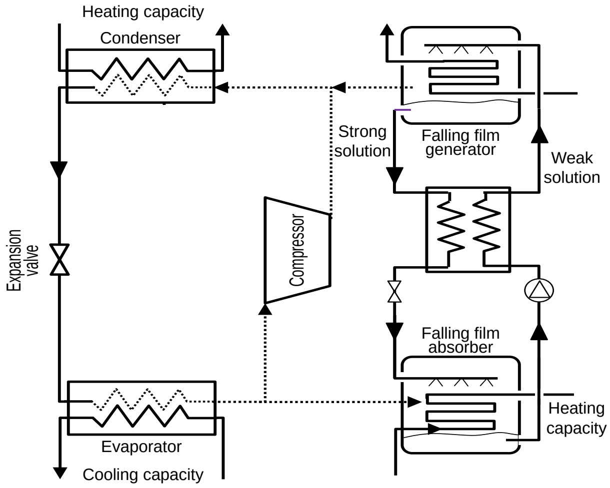


Figure 1-8: Absorption - compression hybrid

3.3.4 Current development

3.3.4.1 Thermo acoustic (TA) type

The acoustic energy is subsequently being used in a TA heat pump to upgrade waste heat to usable process heat at the required temperature. Figure 1-9 below shows the total system. The TA engine is located at the right side and generates acoustic power from a stream of waste heat streamed at a temperature of 140 °C. The acoustic power flows through the resonator to the TA heat pump. Waste heat at a temperature of 140 °C is upgraded to 180 °C in this component. The total system can be generally applied into the existing utility system at an industrial site.

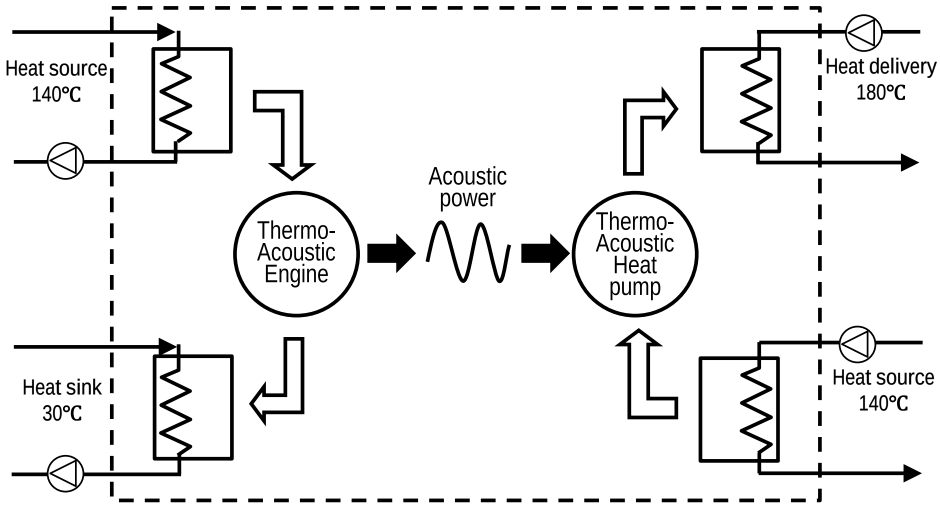


Figure 1-9: Thermo-acoustic heat pump

3.3.4.2 Active magnetic regenerator

Magnetic heat pumps operate based on the magnetocaloric effect. The effect refers to a phenomenon exhibited by certain magnetic materials in which the magnetic material heats up when placed in a magnetic field and cools down when removed from the field as shown in Figure 1-10. Magnetic heat pump technology is able to achieve uniform and instantaneous temperature changes by applying a changing magnetic field to a solid magnetic material. In this way, magnetic heat pumps are able to approach near-ideal refrigeration cycles.

The driving force in magnetic heat pumps is the circulation of the heat exchange medium and the displacement driving force of the magnet that applies the changing magnetic field to the magnetic material. Therefore, compressors are unnecessary. Since magnetic heat pumps do not need compressors, they have less vibration and noise. Furthermore, since these pumps do not use refrigerants such as Freon or Freon substitutes, they are more environmentally friendly.

One problem with magnetic heat pumps is that the inflow and outflow of heat that results from the magnetocaloric effect gets absorbed by the lattice system, which has a high specific heat, and results in a small temperature change of only a few degrees Celsius. Furthermore, it is also difficult to obtain a sufficient surface area for heat transfer, which makes it difficult to increase the heat transfer efficiency. Several reasons why magnetic heat pumps have not yet been successfully commercialized include the fact that magnetic heat pumps have lower performance and higher cost compared to existing refrigerators that are used at room temperature and, in addition, the lack of sufficient research and development work regarding magnetic heat pumps, including their materials.

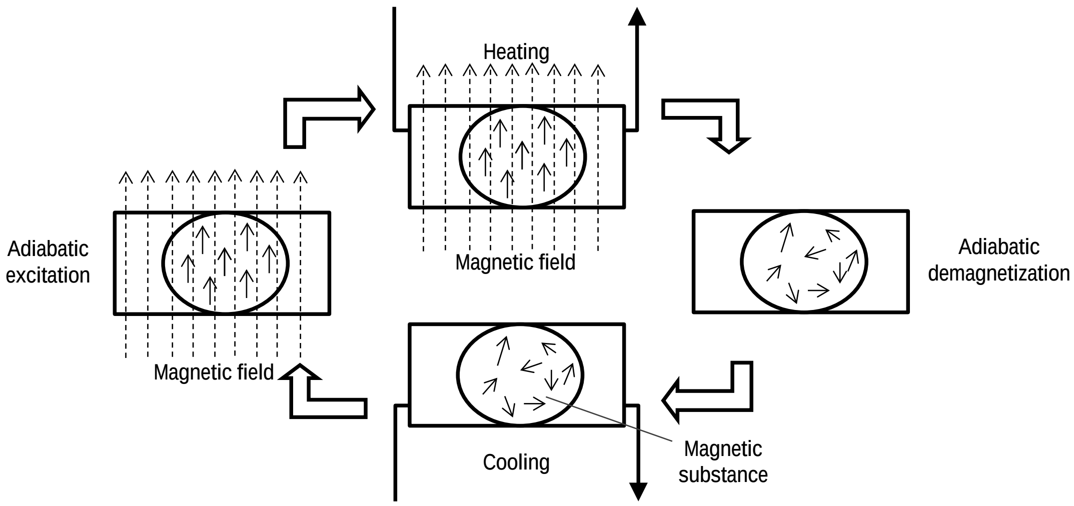


Figure 1-10: Active magnetic regenerator [HIRANO, 2018]

3.4 Practical Application of Industrial Heat Pump Technologies at Different Temperature Levels

Figure 1-11 shows a technological development trend for high temperature HPs from conventional to future technologies. Heating, ventilation, and air-conditioning (HVAC) is the most common technology applied for temperatures below 100 °C. High temperature technologies of the hot water heat pump system are already in commercial use up to 120 °C.

To increase the use of IHPs in industry fields, it is necessary to develop advanced HP technologies with higher temperature operation as well as larger heating/cooling capacity. Hot air heat pumps and MVR heat pumps have already been in commercial use for temperatures above 120 °C, with applications for sterilization, drying, distillation, and concentration processes in industry. A large amount of heat demand is obtained at the level above 165 °C in various industrial fields. Use of the combined heat pump system of steam generation through MVR and TVR for heat recovery could be expected to grow, thereby increasing IHP market share.

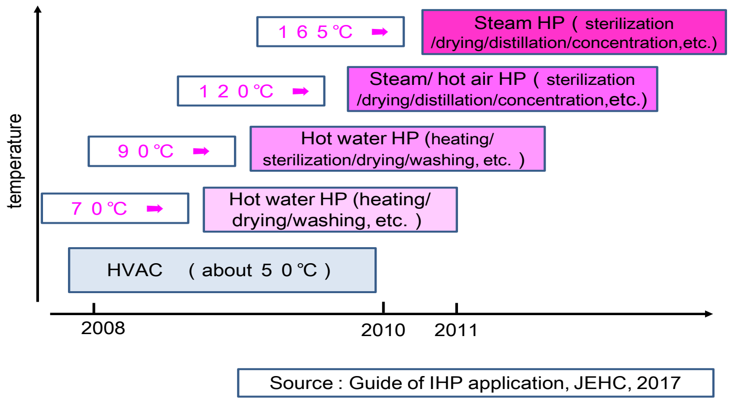


Figure 1-11: Application for high temperature use of IHP

4 Good Practices of IHP Application in Japan

4.1 Information Matrix of Good Practices

IHPs have been mainly applied in food production and agricultural fields in Japan. To increase the use of IHPs in various industrial fields, it is necessary to develop knowledge and information about their merits in different fields. The number of samples for good practices should be increased to construct an IHP database based on available existing information. Information and data on the technological superiority of the heat pump and installation effects from energy, environmental, and economical aspects are useful to support mutual communication between manufacturers and end users, as well as between decision makers for key stakeholders in industry and policy makers. We collected samples of good practices as much as possible and obtained 112 different samples by surveying the literature, including 27 samples reported by the previous Annex 35/13. Table 1-3 contains a list of literature references for all samples: motor driven heat pumps of mechanical heat pump (MHP) and mechanical vapour recompression (MVR) systems from No. 1 to No. 98, and absorption type heat pumps from No. 99 to No. 112.

Table 1-3: Literatures for 112 samples

Literature	Sample number	Number of Annex 35/13
Examples of heat pump installation in industrial sector, JEHC	No.1 ~ 19	No.1 ~ 19
Future Ages, Use More Electricity for Production Vol.5,JEHC (Vol.2,3.4.5)	No.20 ~ 48	No.20 ~ 26
ELECTROHEAT HANDBOOK, JEHC, 2011	No.49 ~ 62	No.49
Journal of Electro-heat, JEHC	No.63 ~ 88	
Seminar materials of JSRAE	No.89 ~ 96	
Process Innovation of Food Factory, JEHC	No.97	
Catalogue of Mitsubishi Electric Corporation	No.98	
Catalogue of Ebara Refrigeration Equipment & Systems Co., Ltd.	No.99 ~ 100	
HEAT PUMPS (1987 International Energy Agency Heat Pump Conference)	No.101 ~ 110	
Hitachi Hyouron Vol.89 No03 (2007) Vol.92 No03 (2010)	No.111 ~ 112	
TOTAL	112	27

To distinguish the relative merits among samples, it is necessary to develop a matrix table of key information on comparisons for 112 good samples. The matrix is structured by key information on technological performance of the heat pump as well as installation effects of energy, environment, and economic aspects among different samples. It is composed of identification, installation, technology and system, and effects of installation. A sample is identified by number, annex quotation, project name, and reference in the matrix. Installation is general information on IHP applications such as industry, process applied, location, year of installation, user name, and manufacturer/constructor/consultant.

The basic information needed to understand the technological characteristics of IHPs is technology and system. Effects of installation are very important information for customers who intend to install IHPs. The following items are required as information on the characteristics of IHP technology and system, as well as effects of IHP installation.

- Characteristics of technology and system
  - Heat pump technology
  - Heat pump system
  - Working fluid (refrigerant)
  - Compressor
  - Heating/cooling capacity [kW]
  - Heat sink (In and Out) [°C]
  - Heat source (In and Out) [°C]
  - Heat storage
  - COP
  - Operation hours per year
- Effects of installation
  - Energy savings
  - CO_2 emission savings
  - Installation cost
  - Subsidies
  - Energy cost savings
  - Annual operation and maintenance cost
  - Payback period
  - Additional effects

The above data are investigated for 112 samples, but the amount of data is limited for some items after the investigation. We are obliged to select items which have sufficient data for comparing differences in sample information. Reliable data needed for the comparison can be obtained by the following items.

- Characteristics of technology and system
  - Heat pump technology
  - Heat pump system
  - Working fluid (refrigerant)
  - Compressor
  - Heating/cooling capacity [kW]
  - Heat sink (In and Out) [°C]
  - Heat source (In and Out) [°C]
  - Heat storage
- Effects of installation
  - Energy savings
  - CO_2 emission savings
  - Energy cost savings
  - Additional effects

Table 1-4 is a matrix obtained for 112 good practices of IHP applications in Japan. Key items for identification, installation, technology and system, and effects are listed in a column. Data of each item for 112 samples are indicated in a row.

Table 1-4: Matrix of good practices for 112 samples

4.2 Analytical Results of Matrix for MHP and MVR

Based on the matrix, we drew analytical figures for installation, technology and system, and effects. The following show analytical results of 98 samples for MHP and MVR.

4.2.1 Installation

4.2.1.1 Industries

Figure 1-12 shows the number of samples installed in different industrial sectors. Food products sector is suitable for IHP application on temperature level and heat demand. The share is dominant in the number, approximately 40% among the total samples, followed by machinery, chemicals, and electronics in that order

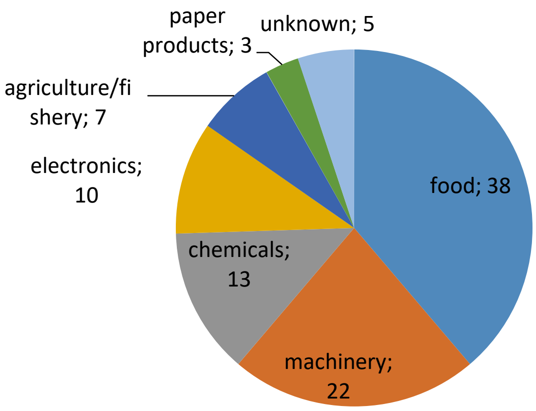


Figure 1-12: Industrial sectors of IHP application (total: 98 samples)

4.2.1.2 Process applied

Figure 1-13 shows the number of samples for each applied process. HVAC is the most basic system of heat pump application, indicated as the largest number among the processes applied as shown in Figure 1-13; heating and heating and cooling follow in that order. The higher ranking three processes occupy approximately 70 percentages of the total number.

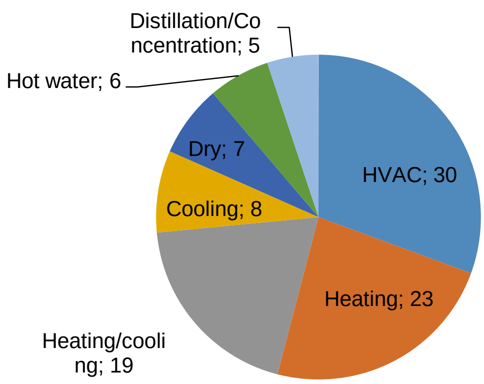


Figure 1-13: Processes applied of IHP (total: 98 samples)

4.2.1.3 Industry vs. process applied

Figure 1-14 shows the distribution of sample number for industry vs. process applied of IHP. HVAC is mainly promoted in machinery, chemicals, and electronics industries. The number of heating/cooling systems is dominant in the food products industry. Heating and hot water supply are widely used in industries such as paper products, chemicals, machinery, and food products.

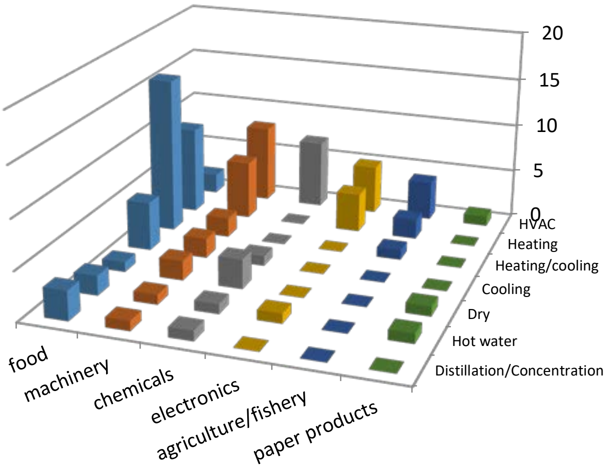


Figure 1-14: Distribution for industry vs. process applied of IHP (total: 98 samples)

4.2.1.4 Location (site)

Japan has four distinct seasons with a climate ranging from subarctic in the north to subtropical in the south. Conditions are different between the Pacific side and the Sea of Japan side. Northern Japan has warm summers and very cold winters with heavy snow on the Sea of Japan side and in mountainous areas. Eastern Japan has hot and humid summers and cold winters with very heavy snow on the Sea of Japan side and in mountainous areas. Western Japan has very hot and humid summers (with temperatures sometimes reaching 35 °C or above) and moderately cold winters.

Japan is a long island and is divided into seven areas and 47 regional governments as follows;

(1) Hokkaido area
(2) Tohoku area (Aomori, Iwate, Akita, Miyagi, Yamagata, Fukushima)
(3) Kanto area (Ibaraki, Tochigi, Gunma, Saitama, Chiba, Tokyo, Kanagawa)
(4) Chubu area (Yamanashi, Nagano, Niigata, Toyama, Ishikawa, Fukui, Shizuoka, Aichi, Gifu)
(5) Kinki area (Mie, Shiga, Kyoto, Osaka, Hyogo, Nara, Wakayama)
(6) Chugoku/Shikoku area (Tottori, Shimane, Okayama, Hiroshima, Yamaguchi, Kagawa, Ehime, Tokushima, Kochi)
(7) Kyushu area (Fukuoka, Saga, Nagasaki, Kumamoto, Oita, Miyazaki, Kagoshima, Okinawa)

Figure 1-15 shows a distribution of locations where a sample is installed. The largest number of installations is in the Chubu area, followed by Kanto and Kinki in that order. They are central areas of the industrial zone and are the most highly populated areas in Japan.

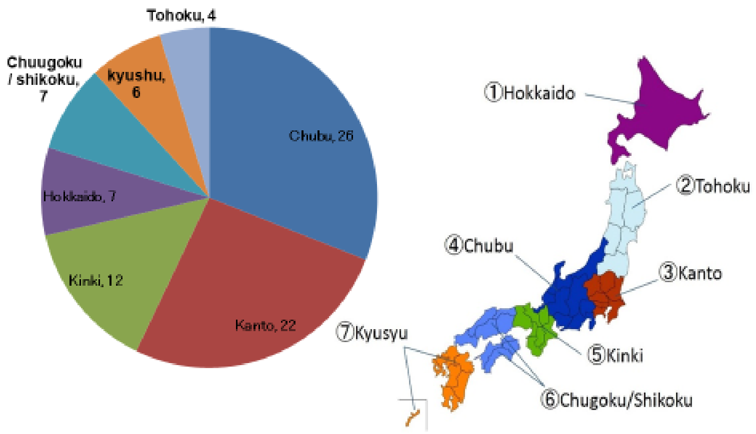


Figure 1-15: Location of IHP installations (total: 84 samples)

4.2.2 Technology and System

4.2.2.1 HP technology

Generally, industrial heat pumps are classified into four types, such as closed-cycle MHPs, open-cycle MVR heat pumps, open-cycle TVR heat pumps and closed-cycle AHPs. Closed-cycle MHPs use mechanical compression of a refrigerant to achieve temperature lift. Most common mechanical drives are electric motors.

Closed-cycle MHP is the most popular technology in commercial use, applied for 94 samples as indicated in the matrix. The other is open-cycle MVR accounting for four samples.

4.2.2.2 HP system

There are many different types of HP systems. Figure 1-16 indicates the number of each system installed. “Air source HP chiller” is the largest application system, 25 percentages of total number. “Water source HP chiller,” “Water source hot water supply HP” and “Water cooled chiller” are also popular HP systems installed in industry.

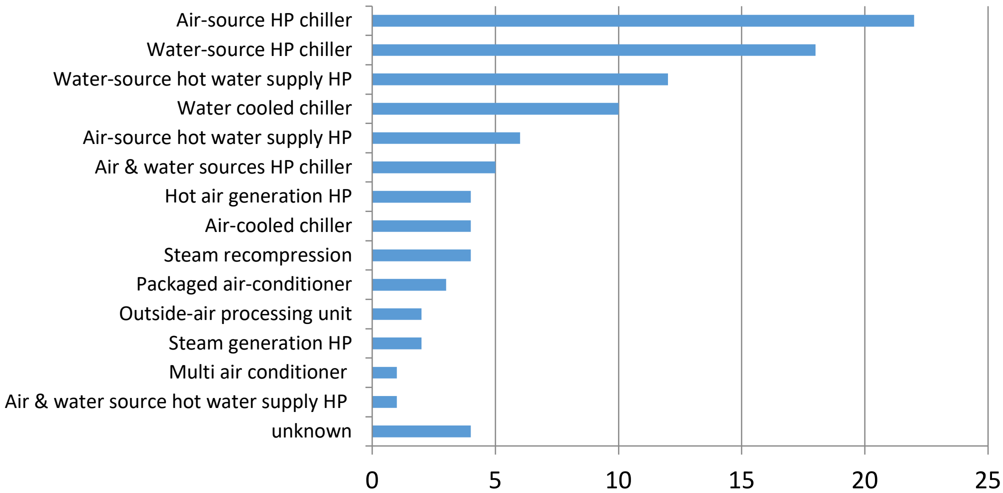


Figure 1-16: HP systems applied (total: 98 samples)

4.2.2.3 *Industry vs. system*

Figure 1-17 shows the distribution of sample number for industry vs. HP system. Air source HP chiller is mainly installed in machinery, foods, and chemical industries. The number of water source hot water supply HP is dominant in the foods industry.

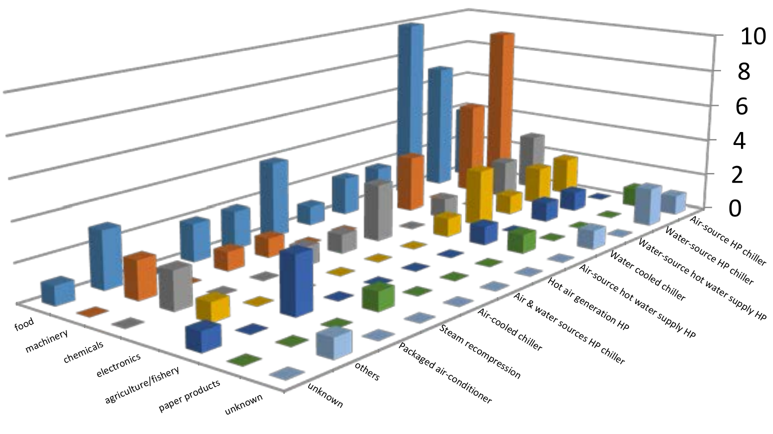


Figure 1-17: Distribution for industry vs. HP system

4.2.2.4 *Compressors*

MHP is the most basic technology and is mainly classified into five different types of compressors such as scroll, reciprocate, rotary, turbo (centrifugal) and screw. The scroll type of compressor is applied for small and medium size heat capacity up to 100 kW, reciprocate and rotary types up to approximately 500 kW, turbo up to 2 MW, and screw type up to 5 MW. Figure 1-18 shows the distribution of number for compressors applied. Rotary is the highest number, followed by reciprocate, turbo, screw, and scroll in that order.

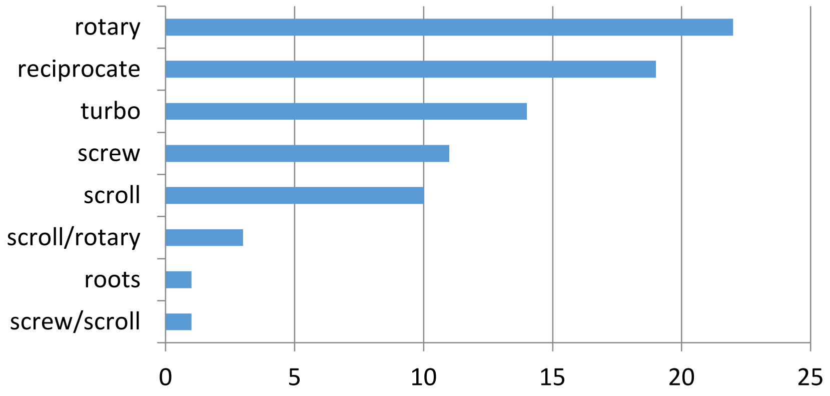


Figure 1-18: Compressor of HP system (total: 81 samples)

4.2.2.5 *Working fluids or refrigerants*

Figure 1-19 is the distribution of number for working fluids or refrigerants. The number of R410A is the most predominant, with CO_2 and R134a following it in that order. The number of working fluids, except Freon system refrigerants, is 20 samples for CO_2 and one sample for steam.

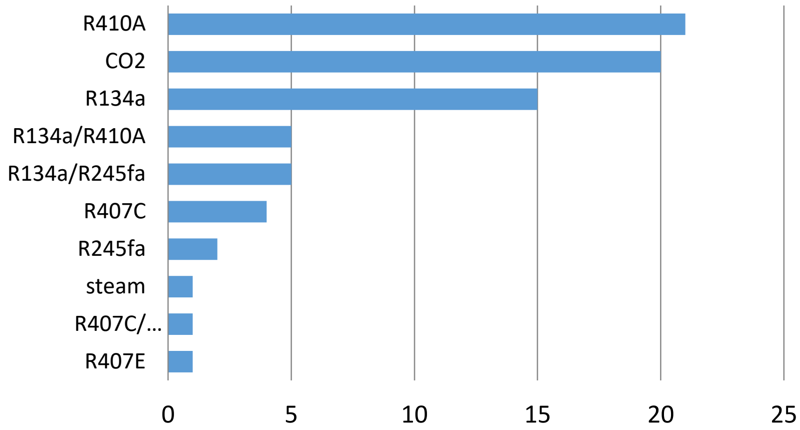


Figure 1-19: Fluid liquids of HP system (total: 75 samples)

4.2.2.6 *Heating/cooling capacity*

The heating/cooling capacity of IHPs is decided by the temperature level of the heat source/sink as well as heat capacity. The water source heat pump can attain high COP because of the high performance of heat exchange, heat recovery, and simultaneous heating/cooling. The heat capacity is widely ranged in commercial use from 20 kW to several MW. The air source heat pump has some merits for installations because it has fewer foundation restrictions, requires less piping work, and costs less to construct. However, its heat capacity is small, ranging from 5 kW to 200 kW, compared with the water source heat pump.

Figure 1-20 shows the distribution of heating/cooling capacity for good practices. The heating/cooling capacity means a total system capacity of the plural number of units. The range of capacity is rather wide from 6 kW to nearly 4,000 kW. The number of large capacity over 1,000 kW is only five among 60 samples.

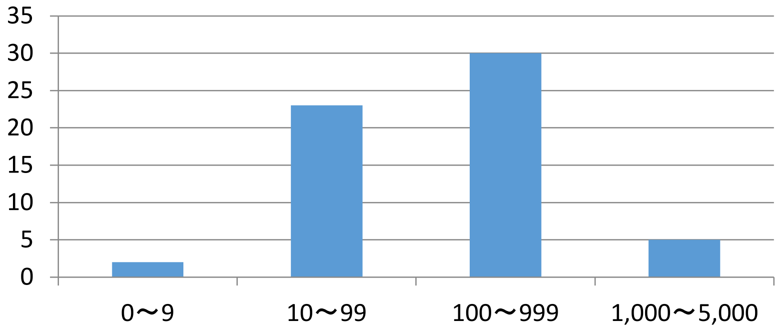


Figure 1-20: Heating/cooling capacity of IHP system (total: 60 samples)

4.2.2.7 Supply temperature

Distribution of supply temperature is shown in Figure 1-21. Supply temperature is ranged from 5 to 120 °C. The number of samples is predominant in the range of temperature level of 60 to 69 °C. There are only five samples available over 100 °C, although a high temperature heat pump is expected to be installed in commercial use.

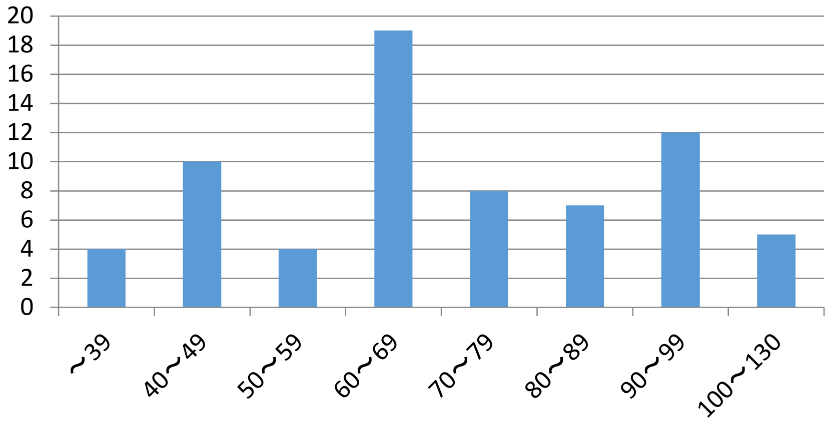


Figure 1-21: Supply temperature of IHP system (total: 69 samples)

4.2.2.8 Process applied in supply temperature

Figure 1-22 shows the number of samples for processes applied at different temperature levels. Supply temperature range of 40 to 100 °C are widely applied for heating and heating/cooling processes. Higher temperature range of 70 to 130 °C are applied mainly for dry processes.

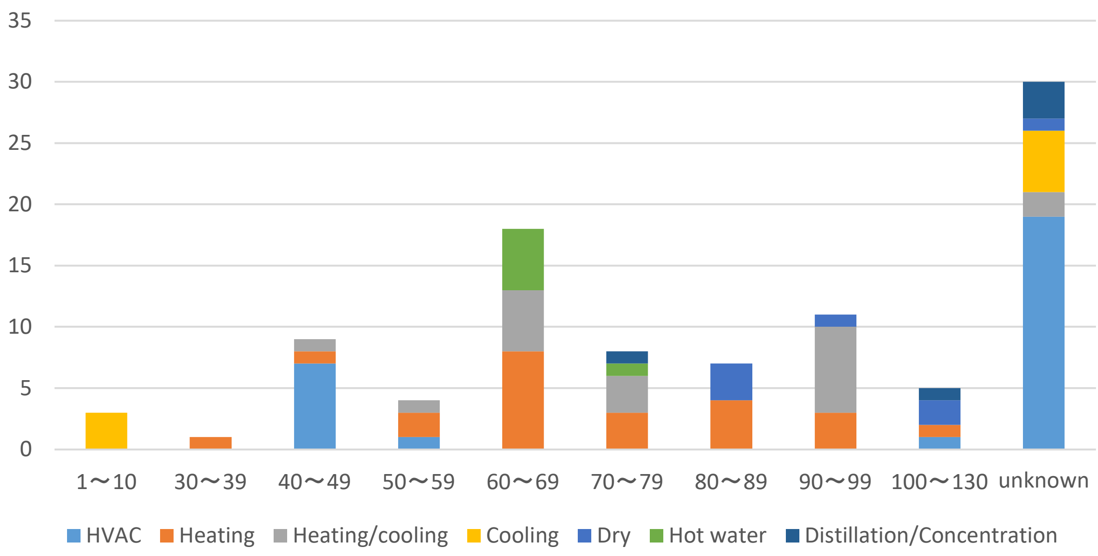


Figure 1-22: Number of processes applied in different supply temperatures

4.2.2.9 Heat sources / heat storage

Figure 1-23 shows distribution of heat source and heat storage used for the system. Simultaneous heating/cooling or outdoor air is the most predominant in the number of installations among different heat sources, occupying 70% of the total heat source samples. Significant energy savings are expected by simultaneous heating/cooling and skilful waste heat recovery. The exhaust heat recycling system is mainly installed in chemical, machinery, and electronic industries.

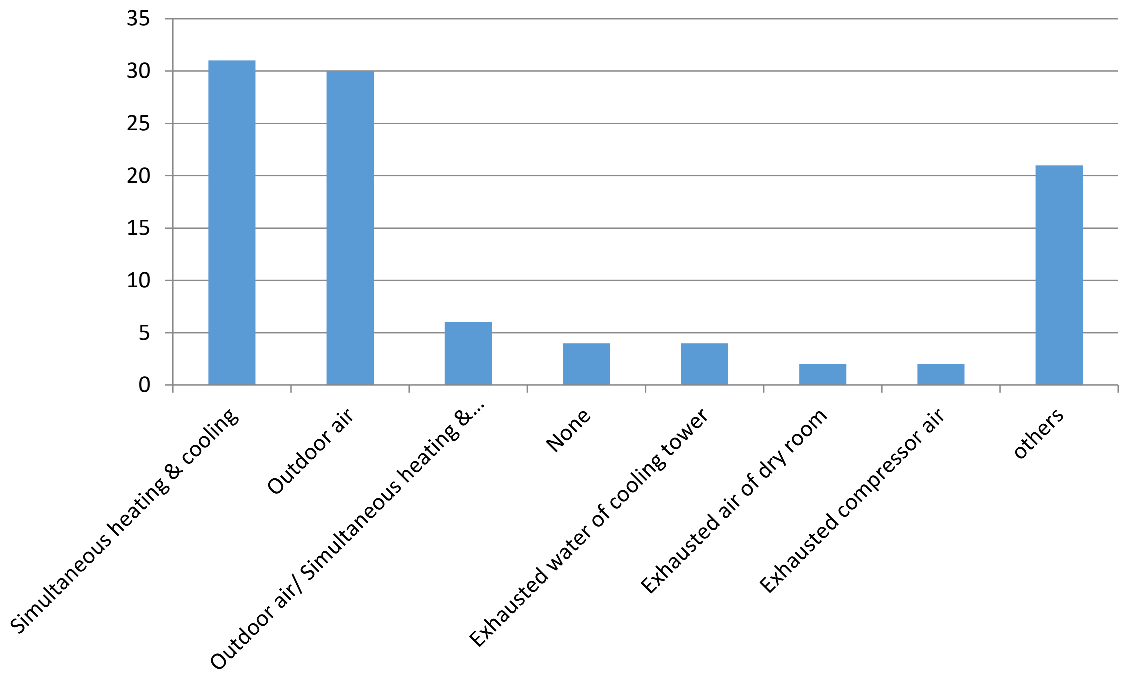


Figure 1-23: Heat source and heat storage applied for the system (total: 98 samples)

Forty-seven samples adopted the heat storage system to improve system efficiency as shown in Figure 1-24. The heat media of the storage system are hot water, cold/hot water, ice, etc. The number of samples of heat pumps applied for hot water storage is 23.

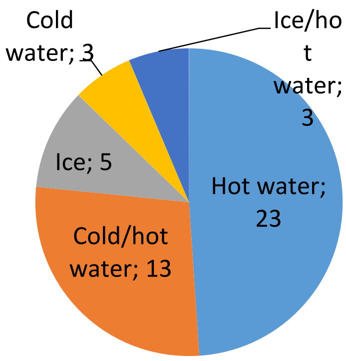


Figure 1-24: Heat media of heat storage system (total: 47 samples)

4.2.3 Effects

4.2.3.1 Savings energy

The IHP has many merits for satisfying customers including energy saving, CO_2 emission saving, energy cost saving, etc. Figure 1-25 shows the distribution of energy saving rate when IHP is installed into commercial use. The saving rate is widely achieved from 5 to 79%, and an average rate is estimated to be 42% as shown in Figure 1-25.

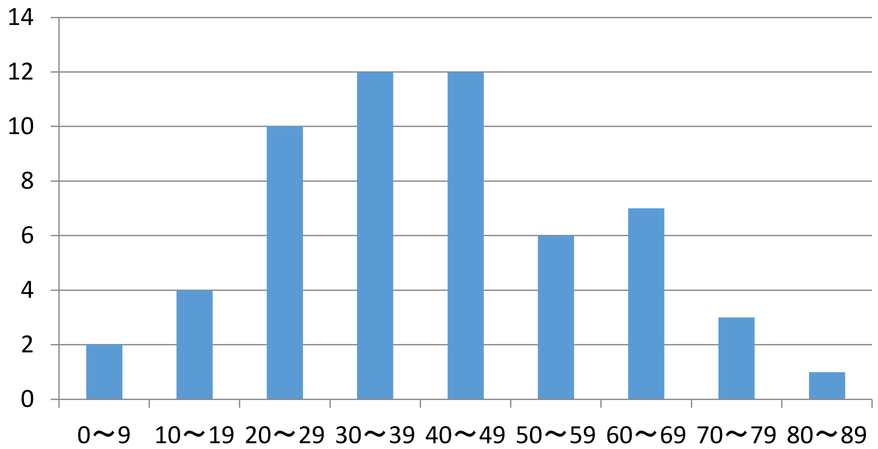


Figure 1-25: Effect of energy savings (total: 57samples)

4.2.3.2 CO_2 emissions savings

IHP also has merit for improving CO_2 emissions as well as saving energy. Figure 1-26 shows distribution of the reduction rate for CO_2 emissions. The rate of CO_2 reduction is higher than the primary energy saving. The highest value is over 80% and average rate is estimated to be 49%.

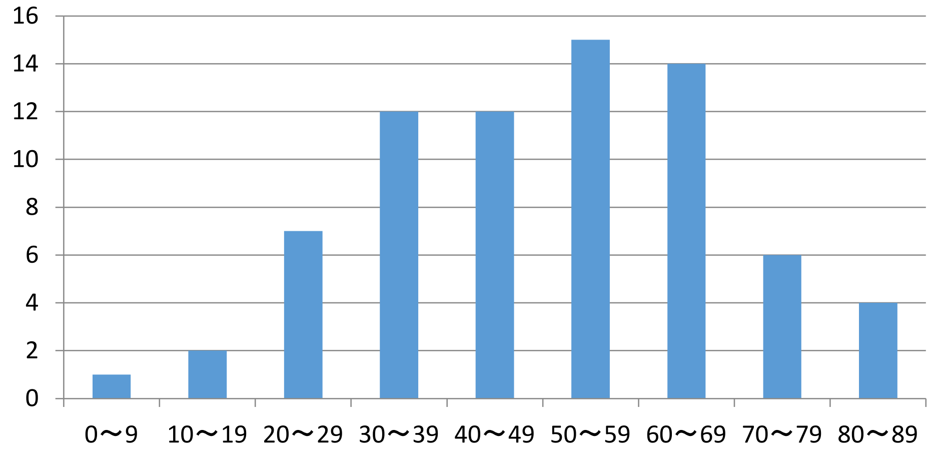


Figure 1-26: Effect of CO_2 emissions savings (total: 73 samples)

4.2.3.3 Savings energy cost

The energy cost of the system is reduced by the installation of an efficient IHP owing to the saving in fossil fuels. Figure 1-27 shows the distribution of energy cost saving rate for 44 samples. The energy cost saving has the same trend of CO_2 reduction. The average rate of energy cost savings is estimated to be 52.5%.

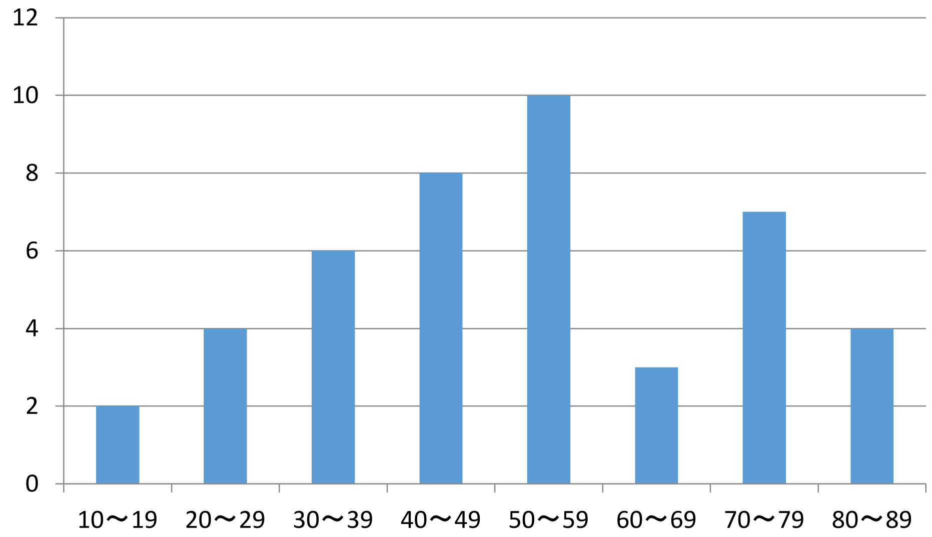


Figure 1-27: Effect of energy cost savings (total: 44 samples)

4.3 Analytical Results of Matrix for Absorption Heat Pumps

The 14 samples shown in the bottom of the matrix are the second type of absorption heat pump.

4.3.1 Industry vs. system

Of the 14 samples given, the pump installation sites are specified for four of the total. Two of those sites are associated with food (liquor production) and machinery (KYB Corporation), while the remaining two are related to chemicals (JSR Corporation and Tsumura & Co.). Of the 10 which are not specified, the heat source for nine of them is vapour from the top of distillation towers; thus, they are assumed to fall into the chemicals category.

4.3.2 Working fluids or refrigerants

Common working fluids for absorption heat pumps are water as a refrigerant and aqueous lithium bromide solution as an absorption solution. All of 14 samples use water as a refrigerant and aqueous lithium bromide solution as an absorption solution. Based on this fact, it is safe to say that the utilized refrigerant has no potential of contributing to global warming compared with fluorocarbon refrigerants.

4.3.3 Heating capacity

The 14 samples have heating capacities ranged from 150 kW to 6,420 kW. A notable aspect of absorption heat pumps is that, because they do not require a compressor, they can be designed for a wide range of heating capacities simply by varying the size of the heat exchanger.

4.3.4 Supply temperature

The absorption heat pump supply temperature increases as the heat source temperature increases and cooling water temperature decreases. Supply temperatures for the 14 cases ranged from 111 to 150 °C and they were used to produce steam.

4.3.5 Process applied in supply temperature

For No. 99, the steam generated by JSR Corporation's absorption heat pump is 133 °C, and it is reused as a distillation tower heat source. For No. 100, the steam generated is 124 °C, and it is also reused as a distillation tower heat source. For No. 109, the steam generated by the absorption heat pump at KYB Corporation's Gifu Minami Plant is 137 °C, and it is reused as a heat source for product cleaning, coating, heating, and painting processes. For No. 100, the steam generated at the Tomakomai Plant of Godo Shusei Co., Ltd., is 112 °C, and it is also reused as a distillation tower heat source.

4.3.6 Heat sources

Of the 14 samples, distillation tower-top steam exhaust heat is the heat source for seven, alcohol vapour exhaust heat is the source for two, gas engine exhaust heat is the source for another two, and the remaining two have other exhaust heat sources.

4.3.7 Energy savings

Vapour compression heat pumps require electricity to power a compressor. In contrast, the amount of electricity needed to run an absorption heat pump is kept low because it is heat-driven. In addition, when exhaust heat is used as the driving heat source, the amount of electricity needed to power the device is essentially zero; thus, energy usage can be reduced by approximately 85% when compared with an equivalent amount of steam obtained from a boiler.

4.3.8 CO_2 emission reduction

For No. 97, CO_2 reduction at Tsumura & Co. is 300 t/year; for No. 109, CO_2 reduction at KYB Corporation's Gifu Minami Plant is 2,294 t/year; and for No. 110, CO_2 reduction at the Tomakomai Plant of Godo Shusei Co., Ltd. is 5,000 t/year.

5 Summary

The number of application samples reported by the results of Annex 35/13 is insufficient to understand the best practice of heat pump technology and its application in industrial processes used for heating, ventilation, drying, dehumidification, and other purposes. Annex 48 is planned as a follow-up annex from the previously completed Annex 35/13. The goal of the new annex is to concentrate on the development and distribution of condensed and clear information materials for policy makers, associations, and industries.

Task 1 aims to populate a heat pump database which is used by stakeholders to select the best practice. The following Task 1 activities are performed to achieve the objectives.

- Up-to-date heat demands of different industrial sectors are investigated to estimate the market potential of IHPs.
- One-hundred and twelve good practices have been collected from all samples, including both the Annex 35/13 report and the new investigation of Annex 48 in Japan.
- Information matrix is developed to be structured by key information on the technological performance of heat pumps as well as installation effects of energy, environmental, and economical aspects among different samples.
- The matrix is analysed to understand the present status of IHP applications and to select excellent application opportunities.

The above information can provide data for a database on industrial heat pumps. However, selection of the best practice from all samples of good practices is needed in order to provide decision makers with information and knowledge about the installation of IHP technologies. We need to develop criteria and methodology to select the best practice of IHP applications. Structuring information on industrial heat pumps based on the results of Task 1 is analysed in Task 2.

6 Literature

[HIRANO, 2018] Naoki Hirano, „Development of free refrigerant heat pump using active magnetic regenerator“, Housing and Electricity Vol. 30, 2018

[JEHC,2016] Database of Industrial and Commercial Heat Pumps, JEHC,2016

[METI, 2014] General Energy Statistics, METI, 2014